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OPTIMIZATION OF THE NUMERICAL MODEL AND STUDY OF THE APPLICABILITY OF THE MODEL FOR DIFFERENT TYPES OF BUILDINGS FROM BUCHAREST

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1 INTRODUCTION

The title of the doctoral thesis is "Optimization of trigeneration systems with reciprocating internal combustion engines as prime movers, with applicability on different types of buildings in Bucharest".
The general objective of the scientific research project proposed in the thesis is the optimization of trigeneration systems having as primary source the internal combustion engines, in terms of possibilities and operating strategies of the equipment in the system's composition, studying the way in which these systems can be applied with positive impact on different profiles of consumer of thermal energy (heat / cold) and electricity. Residential consumers from apartment blocks, consumers from administrative office buildings, consumers from the type of educational institutions, consumers from the health care building and consumers from the type of commercial spaces in Bucharest or other climatic areas of Romania will be taken into account.
After the preliminary bibliographic study of the scientific works in the field of cogeneration and trigeneration and the analysis of the state of knowledge in the field, which took place within the PPCS, it was passed in the Report 1 - “Modeling the energy processes specific to a system of trigeneration with thermal motors for a building of offices ”in modeling the processes in the trigeneration plant and in writing the equations that govern the thermodynamic processes that take place in the plant. The study in report 1 was divided into two main directions: source and consumer. The scheme of the trigeneration plant was drawn up, the balance equations of the energy flows in the source equipments were written: internal combustion engine, electric generator, thermal boiler, plate heat exchanger, hot water storage tank. The balance equations of the energy flows in the absorption chiller for its components were stated: absorber, boiler, condenser and vaporizer and the balance of the energy flows for the refrigeration system with mechanical vapor compression - the electric chiller - necessary for the peak refrigeration tasks was written. On the consumer side were considered the relations from MC 001 regarding the energy consumption for heating, for the preparation of hot water for consumption, the energy consumption for lighting, the consumption of technological heat, the energy consumption for cooling the spaces and for ventilation. At the end of Report 1, a mathematical model of the annual variation of the thermal efficiency of 5 internal combustion engines within a trigeneration plant was presented, depending on the monthly variation of the thermal energy requirement requested by a residential district consumer in Bucharest. In the Mathcad 15 software, a function called Randam_mot_I (PL, x, i) was created, which calculates the thermal efficiency of an engine when entering a random value of the load required by the consumer, for the cascade mode.
Report 2 - "Energy analysis on the operation of a cogeneration system" presented the approach of several strategies for operating the internal combustion engines within a cogeneration system. The study of the modes of operation of the internal combustion engines was constituted in Article 1 published in the scientific journal Romanian Journal of Civil Engineering, under the title: “Analysis of the efficiency of a cogeneration system with internal combustion thermal engines as prime mover and hot water boiler as peak source” [1]. The work elaborated in collaboration with professors Vlad Iordache, Rodica Frunzulică and Florin Iordache came as a consequence of the research from the first report on the variation of the thermal efficiency at partial load, to which was added the calculation of the useful electric power, as stipulated in the Standard EN 15316. The research continued with the experimental part in which the database from a real cogeneration system of a city network - the municipality of Buzău was procured and processed. The scheme of the cogeneration system serving the city network was drawn up and presented. The numerical model within Article 1, which aims to present, in addition to the individual thermal efficiency of internal

combustion engines, the presentation of the total thermal efficiency of the system and of the overall efficiency (thermal + electric), is run with the parametric values from the economic operator's database. At the end of Report 2, a calculation of the effective mechanical power available at the flange of the crankshaft of the thermal motor was presented, where the electrical generation module is coupled. The calculation was based on the study of the thermodynamic processes of internal ignition engines, on the formula that takes into account the average effective pressure in the engine cylinder, the individual cylinder, the number of cylinders, the engine speed and the number of engine times [2]. The energy study and analysis from the experimental part on the cogeneration system was materialized in the second scientific article presented at the UTCB Doctoral School Conference on 26 October. 2018. Article 2 - "Energy analysis of a CHP plant with internal combustion engines, for a district heating system, based on the information from the annual database" was presented in English and was developed in collaboration with professors Vlad Iordache, Florin Iordache and Anica Ilie [3].

The research continued with Article 3 - "Partial load efficiency analysis of a CCHP plant with RICE and H2O-LiBr absorption chiller" presented at the Climate Congress 2019 [4]. This paper, developed in collaboration with Professor Cătălin Lungu, presents a model for calculating and analyzing the overall efficiency of a trigeneration system, using as the first source three internal combustion engines. Engines operate simultaneously at the same load (mode 3 of operation in Article 1). The trigeneration system provides heat and electricity for the office buildings and data center of an economic operator. The system includes 2 absorption chillers with lithium bromide solution for air conditioning cooling. The system was analyzed for the mode of operation at partial loads of the engines, in summer time. The amount of thermal energy produced is influenced by the energy of the thermal agent needed to reach the kettles (generators) of the two chillers to supply the chilled water to the consumers. A mechanical vapor compression chiller is used for cooling load peaks; Article 3 does not study the intervention of the chiller with mechanical vapor compression. Depending on the variation of the thermal load, the thermal motors are started or stopped, operating at rated capacity or in partial load mode. The thermal efficiency of each engine changes according to the required thermal power, determining the variation of the overall efficiency of the trigeneration system. The electrical efficiency of the system also depends on the operating load of the motors that run the electric generators. The EER factor for the absorption chiller changes depending on the temperature difference of the thermal agent reached in the kettle or the temperature difference on the chilled water circuit (the useful flow), resulting in various partial operating loads of the thermal engine (50%, 75% and 100%) the variation of the overall yield of the trigeneration system. Two simulations of the temperature variation in the external cycles of the absorption chillers were conducted: 1 - decrease of the temperature difference in the boiler of the heating agent, the hot water, which comes from the thermal motors by lowering the boiler entry temperature by one degree and 2 - decreasing the temperature difference in the vaporizer of the cool water (the useful flow) by increasing the outlet temperature to the cold consumers by half a degree. The operational graph for each equipment and operating mode simulated was elaborated on the basis of the thermal loading load of the internal combustion engines and represented the graph of variation of the overall efficiency of the trigeneration system according to the two simulations. Finally, useful conclusions and observations were drawn regarding the optimal functioning of the studied trigeneration system and the overall yield percentages obtained at partial and nominal tasks under the described parametric variations.

The next steps in the present thesis were the creation of consumption profiles for residential consumers in Bucharest, the distribution of consumption by categories of energy consumed (heat, electricity, cold), the annual sum of energies, the dimensioning of a system of trigeneration corresponding to the consumer and the application of the model numerically created in Article 1, model improved and run in Articles 2 and 3, under various operating strategies, in order to achieve the general objective of the thesis, mentioned in the introduction.

2 CONTENT OF THE REPORT 3

2.1 RESIDENTIAL CONSUMER

The residential type consumer is a building located at Cernăuţi street no. 50, bl. D8, sc. 1, Sect.2, Bucharest, building under the care of the owners association. From the point of view of the typology of civil buildings, the building is characterized by:

- the territorial - urban area;
- the mode of living - collectively;
- height regime - S + G + 4E;
- number of stairs - 1;
- seismic class: RsIII according to the technical expertise report;
- climatic zone II - represented by the external temperature of calculation $\theta e = -15\ ^0C$;
- Wind zone II, characterized by the wind speed - 0.20 m / s;
- sheltered building.

The studied block of flats is a building with height regime S + GF + 4E, having the regular shape in plan, consisting of a single section of stairs separated by seismic joints from the neighboring stairs. The section of stairs is 27.00 m long and 16.00 m wide.

The block of flats has a number of 19 apartments, these being considered average conventional apartments (apmc, with an area of 60 m2) and with a number of 2.8 persons per apartment.

Following the calculations made during the energy audit performed on the residential type consumer, the parameters and coefficients used in this report, explained in the following chapters and sub-chapters, have been obtained. They were used in the calculations of hourly energy consumption (average hourly hour) for heating, for preparing hot water for consumption, for lighting, for ventilation and air conditioning; using the parameters and calculation formulas, the hourly consumption profiles of the characteristic day of each month were constructed.

2.2 CONSUMPTION PROFILE

For the residential type the daily consumption profiles were constructed for the following categories of energy consumed:

- DHW (domestic hot water) consumption profile;
- heating consumption profile;
- electricity - lighting consumption profile;
- cooling consumption profile;
- ventilation consumption profile.

We will have 10 consumer profiles:

- thermal DHW consumption profile - represents the hourly thermal energy consumption for heating domestic water;
- electrical DHW consumption profile - represents the hourly electricity consumption required for the circulation pumps in the DHW distribution plant;
- thermal heating consumption profile - represents the hourly thermal energy consumption for heating the spaces;

- electrical heating consumption profile - represents the hourly electricity consumption required for circulation pumps in the heating installation;
- electric consumption profile for lighting;
- thermal cooling consumption profile for cooling the residential spaces of the block of flats;
- electrical cooling consumption profile - represents the hourly electricity consumption for air transport in the air conditioning system;
- heating ventilation consumption profile for the air in the ventilation system, in winter;
- cooling ventilation consumption profile for the air in the ventilation system, in summer;
- electrical ventilation consumption profile - represents the hourly electricity consumption for the air transport in the ventilation system.

Each consumer profile for the residential type involves one, two or three categories of consumed energies: electricity, thermal energy for heating, thermal energy for cooling, all these energies being transferred to the consumer.

The immediate purpose of the elaboration of the consumption profiles is to study the particularities of the consumer, the sum of the consumption by categories of consumed energies and the calculation of the annual primary energy consumed.

The subsequent aim is to dimension a "folded" trigeneration system based on the annual consumption obtained, this being obtained through the graded curve procedure and by using the mathematical model built in the first article and improved in the subsequent articles.

Finally, a comparison is proposed based on the analysis between the trigeneration systems considered and the classical solutions and the results, conclusions and recommendations obtained and observed during the research will be mentioned.

2.2.1 DHW profile - thermal

The daily DHW consumption profile for the residential consumer - block of flats was built on the basis of the specific daily hot water requirement for residential buildings in Table 2.4.25 of the Installation Manual, Sanitary Installations, page 46 [5]. From the table was considered an apartment with closet, washbasin, bathtub and washing machine with a flow rate of 70 l / day, pers.

For the plot of the DHW consumption profile curve during the hours of a day for a person within the residential type, the hourly consumption weights measured and calculated from Figure 2.1, [6] were considered. The DHW consumer profile for residential type consumer, in l / h, is shown on the right-hand side of the graph, in yellow.

The distances in mm were measured to the Residential curve (yellow) and to the upper value of 14 l / h from the graph, the hourly consumption from the graph was calculated, summed at the end of the day (85 liters resulted) and the percentage was calculated of consumption for each hour of the daily total according to the chart, Table 2 1. The percentage of each hour was applied to the 70 daily liters mentioned in the Manual of Installations, Sanitary Installations and deduced hourly consumption in l / h, pers. for the residential type consumer.

The thermal energy consumed for DHW preparation for the residential type building, per hour, is calculated using equation 2.1, according to Mc 001/2, [7]. The DHW hourly consumption profile for the housing block, in kWh / h, is the same for all months of the year and is shown in Figure 2.2.

$$Q_{acm_{oră}}^{rez} = \frac{q_c \cdot N_p \cdot N_{ap} \cdot \rho \cdot c_p \cdot (\theta_{ac} - \theta_{ar})}{3600} \qquad \textbf{2.1}$$

where:
$Q_{acm,oră}^{rez}$ - hourly energy consumption for DHW (kWh/h);
q_c - the specific hourly rate of DHW per person (m^3/h,pers);

N_p - number of persons in an apartment (pers);
N_{ap} - the number of apartments in the block of flats (ap);
ρ - water density at 60 ^{0}C (kg/m^3);
c_p - water specific heat (kJ/kgK);
θ_{ac} - hot water temperature (K);
θ_{ar} - cold water temperature (K).

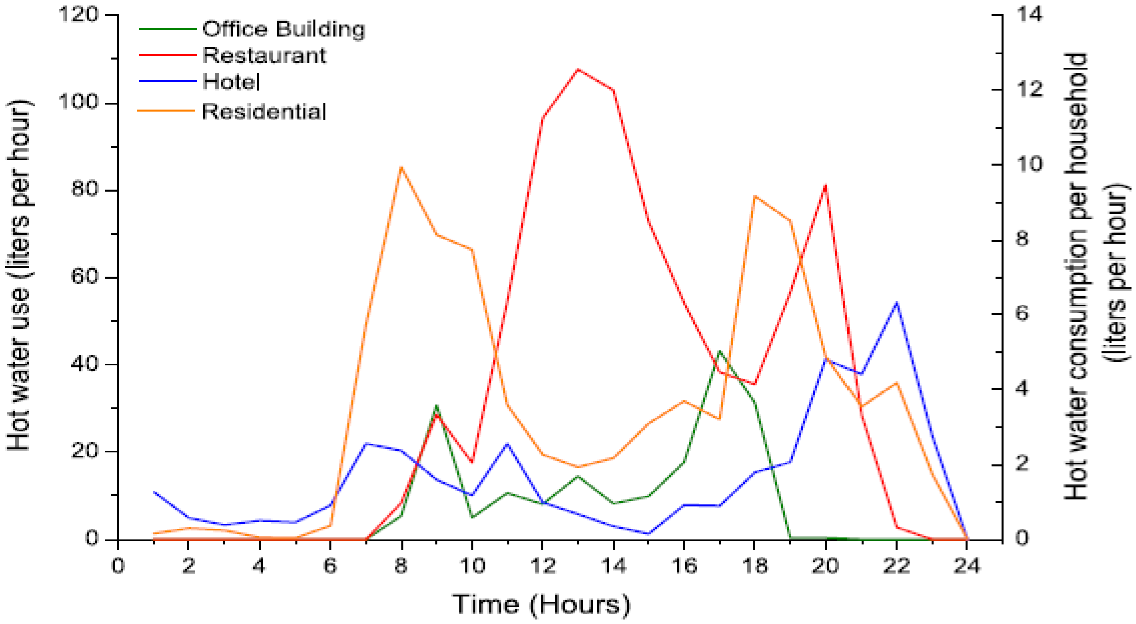

Figure 2.1 Average hourly consumption of DHW profiles [6]

Figure 2.2 Hourly DHW profile - thermal (monthly average hour), residential

Tabel 2-1 Hourly percent participation in DHW consumption per person, residential

hour	percent (%)	l/h,pers
1	0,24%	0,168
2	0,40%	0,280
3	0,32%	0,224
4	0,08%	0,056
5	0,06%	0,041
6	0,48%	0,336
7	7,60%	5,317
8	11,59%	8,115
9	9,59%	6,716
10	9,19%	6,436
11	4,16%	2,910
12	2,64%	1,847
13	1,68%	1,175
14	2,56%	1,791
15	3,76%	2,630
16	4,40%	3,078
17	3,68%	2,574
18	10,79%	7,556
19	9,99%	6,996
20	5,60%	3,918
21	4,24%	2,966
22	4,96%	3,470
23	2,00%	1,399
24	0,00%	0,000
total	100,00%	70,000

2.2.2 DHW profile - electrical

The calculation of the electricity consumption required for circulation pumps, according to Mc001 [7], is performed using the equations in Annex II.3.J, respectively 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 şi 2.8.

$$W_{acm}{}^{rez}_{oră} = W_{ac,d,hidr} \cdot e_{ac,d} \tag{2.2}$$

$$W_{ac,d,hidr} = P_{hidr} \cdot t_{ac} \tag{2.3}$$

$$P_{hidr} = 0{,}2778 \cdot \Delta p \cdot \dot{V} \tag{2.4}$$

$$\Delta p = 0{,}10 \times L_{\max} + \sum \Delta p_{RV,TH} + \Delta p_{App} \tag{2.5}$$

$$L_{\max} = L_{V,\max} + L_{S,\max} \tag{2.6}$$

$$e_{ac,d} = f_e \cdot C_p \cdot \beta_D^{-0,94} \qquad \textbf{2.7}$$

$$f_e = \frac{1{,}50 \cdot b}{0{,}015 \cdot P_{hidr}^{0,74} + 0{,}04} \qquad \textbf{2.8}$$

where:
$W_{acm,oră}^{rez}$ - hourly electricity consumption to operate DHW pump (kWh/h);
$W_{ac,d,hidr}$ - the hydraulic energy required in the system, variable (kWh/h);
$e_{ac,d}$ - circulation pump performance coefficient, 16.4 (-);
P_{hidr} - hydraulic power of the pump, 0.396 (kW);
t_{ac} - the operating time of the pump during the calculation period, 0.6 (h/h);
Δp - pump height, 9.19 (kPa);
$\tilde{V}$ - hot water flow, 0.155 (m^3/h);
L_{max} - the length of the distribution-recirculation route, 58 (m);
$\Delta p_{RV,TH}$ - fittings loss pressure, 2.34 (kPa);
Δp_{App} - equipment loss pressure, 1.05 (kPa);
$L_{V,max}$ - the sum between the length and the width of the building, 27+16 (m);
$L_{S,max}$ - total height of the building, 15 (m);
f_e - factor expressing the efficiency, 63.08 (-);
C_p - a constant, 0.52 (-);
β_D - loading factor, 0.5 (-);
b - factor for existing buildings, 2 (-).

The hourly DHW profile - electrical, in kWh / h, is also identical for all months of the year and is represented in Figure 2.3.

Figure 2.3 Hourly DHW profile - electrical (monthly average hour), residential

2.2.3 DHW profile - electrical

The heating consumption profile for the residential consumer - block of flats was built using the average hourly temperatures for each month of the year, for Bucharest. The consumption profiles for heating have been developed in the form of monthly profiles for January, February, March, April, October, November and December.

The hourly thermal consumption of the building (thermal losses), in kWh / h, was calculated with equation 2.9, using the coefficient of thermal losses of the building H [W / K], equation 2.10 (taken from the calculations made during the energy audit) and the deviation of the temperature between the conventional indoor temperature of calculation, according to [8], and the hourly average monthly temperature.

$$Q_{inc_{oră}}^{rez} = \frac{H \cdot \left(\theta_i - \theta_{med_{oră}}\right)}{1000} \cdot \tau \quad \textbf{2.9}$$

$$H = H_T + H_V \quad \textbf{2.10}$$

where:
$Q_{inc,oră}^{rez}$ - hourly energy consumption for heating (kWh/h);
H - heat transfer coefficient of the building, 2,637.12 (W/K);
H_T - coefficient of thermal transfer by transmission, 1,984.55 (W/K);
H_V - coefficient of thermal transfer by ventilation, 652.57 (W/K);
θ_i - indoor temperature, 293.15 (K);
$\theta_{med,ora}$ - hourly outdoor temperature, monthly average hour, variable, in Bucharest (K);
τ - the time period for the calculation, 1 (h).

The hourly consumption profile for space heating, in kWh / h, during the months of the year, is shown in Figure 2.4.

Figure 2.4 Hourly heating profile - thermal (monthly average hour), residential

2.2.4 Heating profile - electrical

It is considered that the energy recovery from the environment is not performed and only the electricity consumption for the circulation pumps in the heating system, Wd, e is calculated.

The method of simplified calculation of electricity consumption for the distribution of the heating agent, according to Mc001 [9], is performed with equations 2.12, 2.13, 2.14, 2.15, 2.16.

The hydrodynamic load, Phydr, in [W] is calculated based on the volumetric flow rate V and the pumping height Δp required when entering the building. The volumetric flow rate is calculated for the daily heating load, Qn. ΔθHK is the return temperature difference of the heating system, 20 K. ΔLmax is the maximum length of the heating system.

For pregnancy losses, the data provided by the manufacturers or values indicated by the methodology are used [9].

Correction factor for pipeline system, f Sch:- sistem bifilar: $f\,Sch = 1$

- single-wire system: $f\,Sch = 8{,}6 \cdot \dot{m} + 0{,}7$

Correction factor for hydraulic balancing, *f Abgl*:
f Abgl = 1 for hydraulically balanced systems;
f Abgl = 1,25 for hydraulically unbalanced systems.
$\beta_D = 0.5$ loading factor (average load) in the heat distribution system.
$t_H = 1$ h number of heating hours for which electricity consumption is calculated for circulation pumps in the heating system.

$$W_{inc\,oră}^{\;rez} = W_{d,hydr} \cdot e_{d,e} \tag{2.11}$$

$$W_{d,hydr} = \frac{P_{hydr}}{1000} \cdot \beta_D \cdot t_H \cdot f_{Sch} \cdot f_{Abgl} \tag{2.12}$$

$$P_{hydr} = 0{,}2778 \cdot \Delta p \cdot \dot{V} \tag{2.13}$$

$$\dot{V} = \frac{3600 \cdot \dot{Q}_N}{c_p \cdot \rho \cdot \Delta\theta_{HK}} \tag{2.14}$$

$$\Delta p = 0{,}13 \cdot L_{\max} + 2 + \Delta p_{FBH} + \Delta p_{WE} \tag{2.15}$$

$$L_{\max} = 2(L + \frac{B}{2} + n_G \cdot h_G + l_c) \tag{2.16}$$

where:
$W_{\hat{i}nc,oră}^{rez}$ - hourly consumption of electricity for pumping in heating system (kWh/h);
$W_{d,hydr}$ - the hydraulic energy required in the system, variable (kWh/h);
$e_{d,e}$ - the energy factor of the circulation pump, variable (-);
P_{hydr} - hydrodynamic load in the calculation regime, variable (W);
β_D - loading factor, 0.5 (-);
t_H - number of heating hours, 1 (h);
f_{Sch} - correction factor for distribution networks, 1 (-);
f_{Abgl} - correction factor for hydraulic balancing, 1 (-);
Δp - differential pressure of the heating circuit, 43.6 (kPa);
$\tilde{V}$ - hot water flow in the system, variable (m^3/h);
Q_N - variable heating load (kW);
c_p - water specific heat, 4.185 (kJ/kgK);
ρ - water density, 971.83 (kg/m^3);
$\Delta\theta_{HK}$ - the temperature difference in the heating system, 20 (K);
L_{max} - the length of the most disadvantaged circuit in the heating system, 120 (m);
Δp_{FBH} - load loss on heating radiators, 25 (kPa);
Δp_{WE} - differential pressure for supplied heat, 1 (kPa);
L - length of building, 27 (m);
B - width of the building, 16 (m);
n_g - number of heated levels in the calculation area, 5 (-);
h_G - average height of the levels in the calculation area, 3 (m);

l_c - two wires system length, 10 (m).

The hourly profile of heating - electric, in kWh / h, during the months of the year, is shown in Figure 2.5.

Figura 2.5 Hourly heating profile - electrical (monthly average hour), residential

2.2.5 Electricity profile - lighting

For the construction of the electricity consumption profiles, the data were downloaded from the website of the Distribution Operator Enel Muntenia, *e-distribution* [10].

e-distribution manages and modernizes the electricity networks in the three regions Banat, Dobrogea and Muntenia Sud, with the main objective of improving the quality of the distribution service. It annually distributes about 15 TWh of electricity through a network of over 90,000 km.

According to the Procedure for the elaboration and application of the specific consumption profiles in the license area of S.C. ENEL Distribuţie Muntenia S.A. approved by ANRE, the distribution

operator has prepared 24 specific consumption profiles - PSC for consumption places that are suitable for variable consumption in different fields of activity. The consumption categories were divided for each field of activity into two: annual consumption less than 20,000 kWh (noted with the suffix AG1 after the name of the field of activity) and annual consumption between 20,000 kWh and 50,000 kWh (noted with the suffix AG2 after the name activity domain).
The electricity consumption profile for the residential consumer - block of flats was built with the data from Specific consumption profiles type "TERT001", for locurides consumption that is suitable for seasonal consumption, for units of "Tertiary" type [10].

According to the distribution operator:

- the profiles were obtained by analyzing a population of 4848 consumption places, the sample being 401 “Tertiary” consumption places with a 95% confidence level, the sample size being at least 5% of the total analyzed population;
- the confidence rate is ± 20% in 95% of the hourly intervals;
- the sampling methodology used was simple random sampling;
- the profiles were obtained by dynamic modeling by measurements of the profile of the load curves by performing simultaneous recordings (measurements) over a certain period of time to a small number of clients spread over the entire coverage area of the operator;
- the validation was achieved by overlapping the obtained profiles, on the measured real consumption curve and eliminating the major deviations.

For the residential type consumer - housing block the annual consumption is less than 20,000 kWh.
The data downloaded from the e-distribution, [10], are in the form of hourly consumption weights for all days of the month and for all months of the year. The data for the year 2018 were downloaded and they were processed in the sense that the weights given by the operator were applied to the monthly energy consumption for artificial lighting from the energy audit performed on the building. Then for each hour from 1 to 24 was calculated the average consumption of the respective hour in kWh, as can be seen in the columns called "average kWh", respectively columns 5, 8 and 11. Part of the data processing table is presented in Table 2 2, Table 2 3.
The hourly electricity consumption profiles for lighting in kWh, for residential type consumers, during the months of the year, are shown in Figure 2.6. They were built with the average hourly consumption of the month (ie for January with the average consumption of 1 hour from the 31 days of January, with the average consumption of 2 hours from the 31 days of January, with the average consumption of 3 hours from the 31 days of January, etc., until the average consumption of 24 hours from the 31 days of January; then for February, March ... December), according to equations 2.17, 2.18 and 2.19.

$$W_{il_{oră}}^{rez} = \frac{\sum W_{il_{oră,zi}}^{rez}}{N_z} \qquad \textbf{2.17}$$

$$W_{il_{oră,zi}}^{rez} = PSC_{oră} \cdot \frac{W_{il_{an}}}{12} \qquad \textbf{2.18}$$

$$W_{il_{an}} = 6A + \frac{t_u \cdot \sum P_n}{1000} \qquad \textbf{2.19}$$

where:
$W_{il,oră}^{rez}$ - hourly electricity consumption for lighting (kWh/h);
$W_{il,oră}^{rez}$ - the sum of the same hour of the month (1, 2, 3, ... 24) (kWh/h);
N_z - the number of days of the month;

$PSC_{oră}$ - percentage weight of hourly consumption from monthly consumption by *e-distribution*, [10];
$W_{il,an}$ - the annual lighting consumption from the audit report of the building, 15,240 (kWh/an);
6 - specific electricity, 1+5 (kWh/m^2)
A - the total area of the used floor, 2,268 (m^2);
t_u - day / night artificial light usage time, 14.3 (h);
P_n - installed electric power, 114,000 (W).

Figure 2.6 Hourly electricity profile - lighting (monthly average hour), residential

Table 2-2 Hourly electricity - lighting consumption, residential

Ziua	Ora	ian.19		feb.19		dec.19	
		pondere din consumul lunii	consum orar kWh	pondere din consumul lunii	consum orar kWh	pondere din consumul lunii	consum orar kWh
Ziua 1	1	0,000968	1,229	0,001109	1,408	0,000936	1,189
Ziua 1	2	0,000948	1,203	0,001098	1,394	0,000895	1,137
Ziua 1	3	0,000927	1,177	0,001096	1,392	0,000878	1,115
Ziua 1	4	0,000910	1,155	0,001103	1,401	0,000865	1,099
Ziua 1	5	0,000910	1,156	0,001112	1,412	0,000860	1,092
Ziua 1	6	0,000939	1,193	0,001144	1,452	0,000870	1,105
Ziua 1	7	0,000984	1,250	0,001240	1,575	0,000904	1,147
Ziua 1	8	0,001087	1,380	0,001454	1,847	0,000982	1,247
Ziua 1	9	0,001225	1,555	0,001784	2,265	0,001091	1,386
Ziua 1	10	0,001338	1,699	0,002107	2,675	0,001181	1,500
Ziua 1	11	0,001370	1,740	0,002283	2,899	0,001208	1,534
Ziua 1	12	0,001333	1,693	0,002313	2,937	0,001200	1,523
Ziua 1	13	0,001243	1,578	0,002263	2,873	0,001151	1,461
Ziua 1	14	0,001134	1,440	0,002191	2,783	0,001073	1,362
Ziua 1	15	0,001054	1,339	0,002119	2,691	0,001006	1,278
Ziua 1	16	0,001026	1,302	0,002064	2,621	0,001017	1,292
Ziua 1	17	0,001061	1,347	0,002050	2,603	0,001098	1,394
Ziua 1	18	0,001115	1,415	0,002014	2,558	0,001173	1,489
Ziua 1	19	0,001139	1,447	0,001897	2,409	0,001183	1,502
Ziua 1	20	0,001104	1,401	0,001703	2,162	0,001133	1,438
Ziua 1	21	0,001039	1,319	0,001519	1,929	0,001065	1,352
Ziua 1	22	0,000990	1,257	0,001373	1,744	0,000998	1,267
Ziua 1	23	0,000962	1,221	0,001269	1,611	0,000948	1,204
Ziua 1	24	0,000941	1,195	0,001207	1,532	0,000909	1,154
Ziua 2	1	0,000968	1,229	0,001189	1,509	0,000881	1,118
Ziua 2	2	0,000948	1,203	0,001179	1,497	0,000859	1,091
⋮							
Ziua 31	23	0,001039	1,319		0,000	0,001051	1,335
Ziua 31	24	0,000986	1,252		0,000	0,000972	1,235

Table 2-3 Hourly electricity - lighting consumption, monthly average hour, residential

Ziua	Ora	ian.19		feb.19			dec.19	
		consum orar kWh	media orei "i" kWh	consum orar kWh	media orei "i" kWh		consum orar kWh	media orei "i" kWh
Ziua 1	1	1,229	1,211	1,408	1,227		1,189	1,202
Ziua 1	2	1,203	1,188	1,394	1,217		1,137	1,169
Ziua 1	3	1,177	1,175	1,392	1,206		1,115	1,149
Ziua 1	4	1,155	1,165	1,401	1,204		1,099	1,139
Ziua 1	5	1,156	1,164	1,412	1,214		1,092	1,138
Ziua 1	6	1,193	1,208	1,452	1,247		1,105	1,181
Ziua 1	7	1,250	1,328	1,575	1,338		1,147	1,311
Ziua 1	8	1,380	1,570	1,847	1,562		1,247	1,567
Ziua 1	9	1,555	1,898	2,265	1,895		1,386	1,893
Ziua 1	10	1,699	2,196	2,675	2,201		1,500	2,169
Ziua 1	11	1,740	2,357	2,899	2,363		1,534	2,310
Ziua 1	12	1,693	2,386	2,937	2,383		1,523	2,329
Ziua 1	13	1,578	2,343	2,873	2,320		1,461	2,291
Ziua 1	14	1,440	2,271	2,783	2,229		1,362	2,236
Ziua 1	15	1,339	2,185	2,691	2,144		1,278	2,167
Ziua 1	16	1,302	2,105	2,621	2,083		1,292	2,119
Ziua 1	17	1,347	2,076	2,603	2,051		1,394	2,134
Ziua 1	18	1,415	2,035	2,558	2,002		1,489	2,116
Ziua 1	19	1,447	1,919	2,409	1,893		1,502	1,994
Ziua 1	20	1,401	1,725	2,162	1,719		1,438	1,790
Ziua 1	21	1,319	1,536	1,929	1,536		1,352	1,583
Ziua 1	22	1,257	1,389	1,744	1,391		1,267	1,417
Ziua 1	23	1,221	1,297	1,611	1,296		1,204	1,317
Ziua 1	24	1,195	1,239	1,532	1,245		1,154	1,245
Ziua 2	1	1,229		1,509			1,118	
Ziua 2	2	1,203		1,497		....	1,091	
⋮								
Ziua 31	23	1,319		0,000			1,335	
Ziua 31	24	1,252		0,000		......	1,235	

2.2.6 Cooling profile - thermal

The profile of air conditioning consumption for the residential consumer - block of flats was constructed by the method described in the Design, Ventilation and Air Conditioning Guidelines [11]. For an average apartment apmc (60 m^2 useful area) the hourly thermal load was calculated, considering 9 hours of operation of the air conditioning system, respectively between 10:00 and 18:00. According to Mc001 [12], the energy requirement for cooling is calculated by summing the contributions through the opaque and glazed building elements with the heat releases from humans, lighting, office equipment, open space kitchen outlets from which the total energy transferred (through the ventilation air and transmission) between the building and the external environment is reduced by a factor of use of heat losses in the cooling situation.
Maximum thermal load for a a.m.c. was recorded at 12:00, respectively 4347 W. The cold consumed for cooling air conditioning, per hour, is calculated with equations 2.20, 2.21, 2.22, 2.23 and 2.24.

$$Q_{clim_{oră}}^{rez} = \frac{\varphi_{surse} - \eta_R \cdot \varphi_{tr}}{1000} \cdot \tau \qquad \textbf{2.20}$$

$$\varphi_{surse} = N_{ap} \cdot (\varphi_{int} + \varphi_S) \qquad \textbf{2.21}$$

$$\varphi_{tr} = \varphi_T + \varphi_V \qquad \textbf{2.22}$$

$$\varphi_T = H_T \cdot \left(\theta_i + \theta_{med_{oră}}\right) \qquad \textbf{2.23}$$

$$\varphi_V = H_V \cdot \left(\theta_i + \theta_{med_{oră}}\right) \qquad \textbf{2.24}$$

where:
$Q_{clim,oră}^{rez}$ - hourly thermal energy consumption for cooling (kWh/h);
ϕ_{surse} - the total flow provided by the heat sources, for cooling (W);
ϕ_{tr} - total flow transferred between the building and the external environment, for cooling (W);
η_R - using factor of heat losses, for cooling (-);
τ - the time period for the calculation, 1 (h);
N_{ap} - the number of apartments in the block of flats (ap);
ϕ_{int} - heat flow from internal sources in an apartment, 42503 (W/ap);
ϕ_S - heat flow from the sun in an apartment, 32259 (W/ap);
ϕ_T - heat flux transferred by transmission, variable (W);
ϕ_V - heat flow transferred by ventilation, variable (W);
H_T - coefficient of thermal transfer by transmission, 1,984.55 (W/K);
H_V - coefficient of thermal transfer by ventilation, 652.57 (W/K);
θ_i - indoor temperature, 293.15 (K);
$\theta_{med,ora}$ - hourly outdoor temperature, monthly average hour, variable, in Bucharest (K).

The hourly consumption profiles for residential air conditioning, in kWh / h, for June, July, August and September are shown in Figure 2.7.

Figure 2.7 Hourly cooling profile - thermal (monthly average hour), residential

2.2.7 Cooling profile - electrical

The energy consumption for air transport is based on the calculation of the specific electricity consumption [12]. The specific consumption of electricity for the air-conditioned building results from the mediation of the specific consumption for each room through the floor surface. The total electricity consumption for the air transport in an air conditioning system is obtained by multiplying the specific electricity consumption of the fan, with the total surface of the air-conditioned spaces in the building.

The energy requirement for air transport, according to Mc001 [12], is calculated using equations 2.25, 2.26, 2.27, 2.28.

$$W_{clim}{}^{rez}_{oră} = N_{ap} \cdot W_v \cdot S \qquad \textbf{2.25}$$

$$W_v = P_v \cdot \frac{N_h}{1000} \tag{2.26}$$

$$P_v = P_{sp} \cdot V' \tag{2.27}$$

$$V' = \frac{n \cdot V}{S} \tag{2.28}$$

where:
$W_{clim,oră}^{rez}$ - hourly electricity consumption for cooling (kWh/h);
N_{ap} - the number of apartments in the block of flats (ap);
W_v - hourly fan specific electricity consumption (kWh/m^{2}h);
S - climatized area (m^2);
P_v - specific electric power for fan drive (W/m^{2}h);
N_h - number of operating hours at nominal load, 0.3 ÷ 0.6 (h);
P_{sp} - fan specific power,, 0.42 (W/m^3), Anexa II.2.L [12];
V' - air specific flow (relative to the room surface, m^3/m^{2}h);
n - air exchanges number (5 h^{-1}) [11];
V - the volume of the climatized room (m^3/ap).

The values indicated for the specific power of the fan (for the entire air conditioning system) are given in Annex II.2.L [12] depending on the type of installation (the destination of the room) and the energy efficiency of the installations - 0.42 W / m3, h.
The number of operating hours at rated load is considered one hour to result in hourly electricity consumption.
The specific volume flow of air relative to the surface of the room was calculated with the hourly number of air exchanges for various rooms, according to Table 12.8 of the Design Guide [11]. In calculating the electricity consumed for air conditioning, a fan was considered for each of the 19 apartments in the block of flats. The calculation of the electricity consumed for air conditioning, in kWh / h, for the air transport to the residential type consumer is illustrated in Table 2 4.

Table 2-4 Hourly cooling - electrical consumption, monthly average hour, residential

Psp	0,42	W/m3/h	
L	6,35	m	
l	4,75	m	
h	2,8	m	
S	30,163	m2	
V	84,455	m3	
n	5	sch/h	
V'	14,00	m3/m2,h	
Pv	5,88	W/m2,h	
Nh	0,3 ÷ 0,6	h	
Wv	0,001764	kWh/m^2,h	
Qvt_ap	0,053207	kWh/h	1 living/h
Nr apmc	19		
$W_{clim, ora}$_bloc_zi	1,011	kWh/h	

The hourly electricity consumption profile for residential air conditioning, in kWh / h, is shown in Figure 2.8.

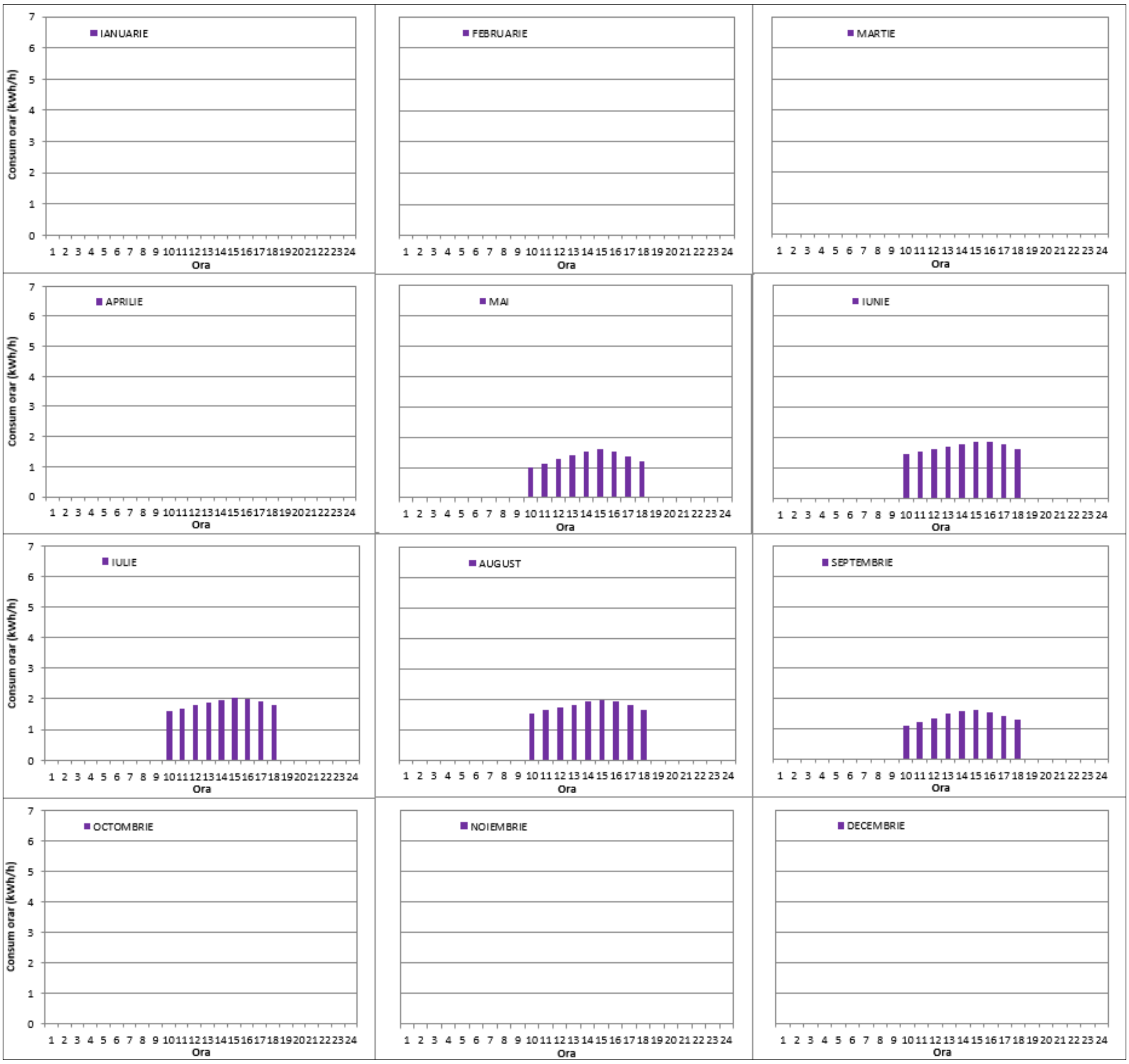

Figure 2.8 Hourly cooling profile - electrical (monthly average hour), residential

2.2.8 Heating - ventilation - thermal profile

The profile of ventilation - heating consumption for the residential consumer was constructed using the average hourly temperatures for each month of the year, for Bucharest and the air inlet temperature, considered to be 2 degrees higher than the indoor temperature, respectively 22 ° C. Ventilation is done without heat recovery.

The heat consumption, in kWh / h, necessary for heating the ventilated air in winter, is determined by equation 2.29. The temperature of the indoor air, and in winter it was considered 20 ^{0}C. The flow, $\dot{G}$, in m3 / h, is calculated with equation 2.30, where the specific flow per person, Gp, is 25 m^3 / h, pers and the specific flow on the surface, Gs, is 2.52 m^3 / h, m^2.

$$Q_{vent,inc}{}^{rez}_{oră} = \frac{\frac{\dot{G}}{3600} \cdot \rho_{aer} \cdot c_{p_{aer}} \cdot \left(\theta_{intro} - \theta_{med_{oră}}\right)}{1000} \cdot \tau \qquad \textbf{2.29}$$

$$\dot{G} = N_p \cdot N_{ap} \cdot G_p + S_u \cdot G_s \qquad \textbf{2.30}$$

where:
$Q_{vent,înc,oră}^{rez}$ - hourly energy consumption for heating - ventilation, (kWh/h);
$\dot{G}$ - air flow for heating - ventilation, 2,774.2 (m^3/h);
ρ_{aer} - air density, 1.205 (kg/m^3);
$c_{p,aer}$ - air specific heat, 1,004 (J/kgK);
θ_{intro} - indoor temperature plus 2 degrees, 295.15 (K);
$\theta_{med,ora}$ - hourly outdoor temperature, monthly average hour, variable, in Bucharest (K);
τ - the time period for the calculation, 1 (h);
N_p - number of persons in an apartment, 2.8 (pers);
N_{ap} - the number of apartments in the block of flats, 19 (apt);
G_p - air specific flow per person for CAI=2 (m^3/h,pers);
S_u - the ventilated useful area (m^2);
G_s - air specific flow per area for CAI=2 (m^3/h,pers).

The hourly profile of ventilation - heating consumption for the residential type consumer, in kWh / h, is shown in Figure 2.9.

Figure 2.9 Hourly heating - ventilation profile - thermal (monthly average hour), residential

2.2.9 Cooling - ventilation thermal profile

The profile of ventilation - cooling consumption for the residential consumer was constructed using the hourly average temperatures for each month of the year, for Bucharest and the air inlet temperature, considered to be 2 degrees lower than the internal temperature, respectively 18 ° C. Ventilation is done without heat recovery.

The heat consumption, in kWh / h, necessary for cooling the ventilated air in summer, is determined by equation 2.31. The temperature of the indoor air, and in summer it was considered 20 ^{0}C. The flow rate, $\dot{G}$, in m3 / h, is calculated according to equation 2.32. The hourly profile of ventilation - cooling consumption for the residential type consumer, in kWh / h, is shown in Figure 2.10.

$$Q_{vent,rac}{}^{rez}_{oră} = \frac{\frac{\dot{G}}{3600} \cdot \rho_{aer} \cdot c_{p_{aer}} \cdot (\theta_{med_{oră}} - \theta_{intro})}{1000} \cdot \tau \tag{2.31}$$

$$\dot{G} = N_p \cdot N_{ap} \cdot G_p + S_u \cdot G_s \tag{2.32}$$

where:
$Q_{vent,rac,oră}^{rez}$ – hourly energy consumption for cooling - ventilation (kWh/h);
$\dot{G}$ - air flow for cooling - ventilation , 2774.2 (m^3/h);
ρ_{aer} - air density, 1,205 (kg/m^3);
$c_{p,aer}$ - air specific heat, 1004 (J/kgK);
θ_{intro} - indoor temperature minus 2 degrees, 291.15 (K);
$\theta_{med,ora}$ - hourly outdoor temperature, monthly average hour, variable, in Bucharest (K);
τ - the time period for the calculation, 1 (h);
N_p - number of persons in an apartment, 2.8 (pers);
N_{ap} - the number of apartments in the block of flats, 19 (apt);
G_p - air specific flow per person for CAI=2 (m^3/h,pers);
S_u - the ventilated useful area (m^2);
G_s - air specific flow per area for CAI=2 (m^3/h,pers).

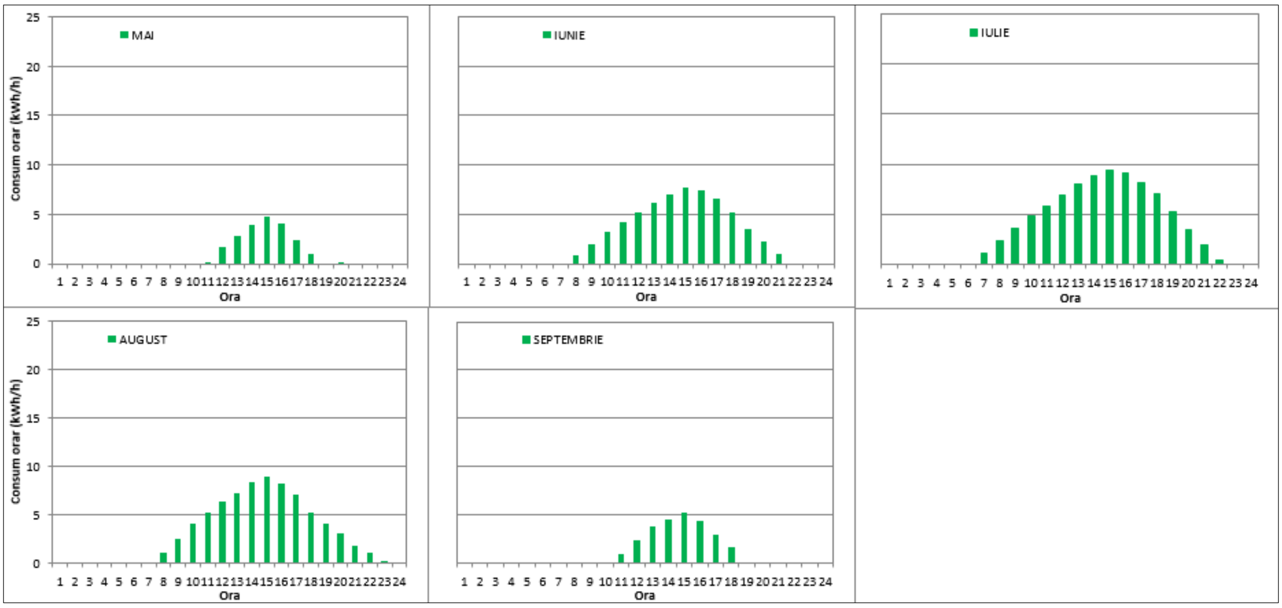

Figure 2.10 Hourly cooling - ventilation profile - thermal (monthly average hour), residential

2.2.10 Ventilation profile - electrical

The electricity consumption for air circulation in the ventilation system is the power consumption of the two pumps: a fresh air supply fan and the fan for extracting pollute air. According to [13], [14], the hourly electricity consumption of the fans is calculated using equations 2.33, 2.34.

$$W_{vent}{}^{rez}_{oră} = 2 \cdot \frac{\Delta p \cdot \dot{G}}{\eta_{vent}} \cdot \tau \qquad \textbf{2.33}$$

$$\dot{G} = N_p \cdot N_{ap} \cdot G_p + S_u \cdot G_s \qquad \textbf{2.34}$$

where:
$W_{vent,oră}^{rez}$ - hourly consumption of electricity for fan drive (kWh/h);
Δp - pressure loss from the ventilation system, 1.15 (kPa);
$\dot{G}$ - air flow for cooling - ventilation , 2774.2 (m^3/h);
η - fan efficiency, 0.7 (-);
τ - the time period for the calculation, 1 (h);
N_p - number of persons in an apartment, 2.8 (pers);
N_{ap} - the number of apartments in the block of flats, 19 (apt);
G_p - air specific flow per person for CAI=2 (m^3/h,pers);
S_u - the ventilated useful area (m^2);
G_s - air specific flow per area for CAI=2 (m^3/h,pers).

The hourly profile of ventilation - electricity consumption for the residential type consumer, in kWh / h, is the same for all months of the year and is represented in Figure 2.11.

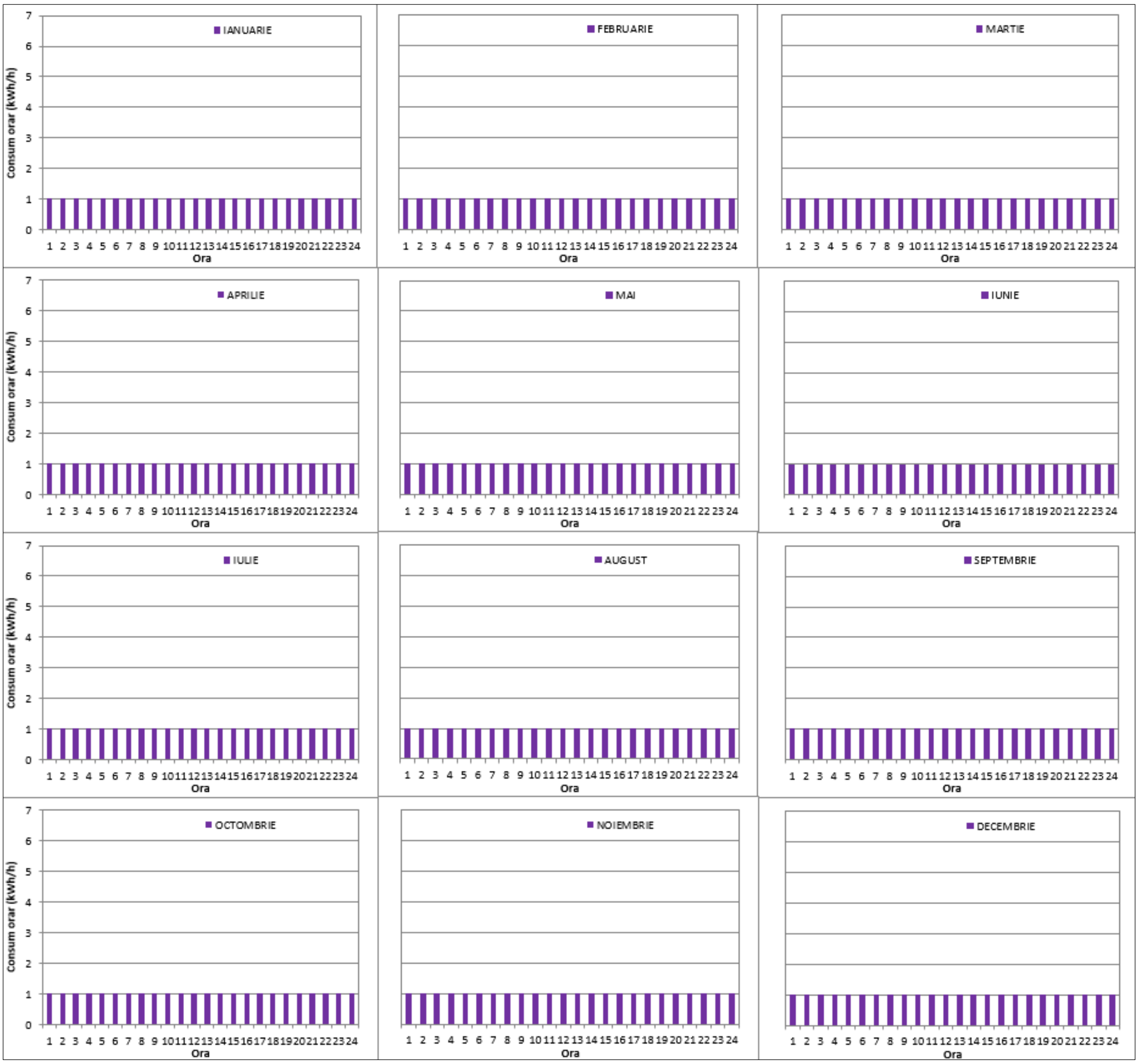

Figure 2.11 Hourly ventilation profile - electrical (monthly average hour), residential

2.2.11 Technological consumption profile

The profile of technological heat consumption for the residential type consumer - housing block is considered null, equation 2.35.
The technological cold consumption profile for the residential type consumer - housing block is considered null, equation 2.36.
The profile of technological electricity consumption for the residential type consumer - housing block is considered null, equation 2.37.

$$Q_{cald\_teh} = 0 \quad \textbf{2.35}$$

$$Q_{frig\_teh} = 0 \quad \textbf{2.36}$$

$$W_{teh} = 0 \quad \textbf{2.37}$$

2.3 ENERGY TRANSFERED BY THE TRIGENERATION SYSTEM

2.3.1 Calculation of total transferred energy

The trigeneration system will produce and transfer to the residential consumer 3 types of energies: electricity, heat - thermal energy for heating and cold - thermal energy for cooling.
The three profiles of the transferred energies resulted from the summation of the hourly consumption calculated and presented in chapter 2.2. The corresponding calculation formulas are presented in Equations 2.38, 2.39, 2.40.
The hourly, monthly average profiles of the transfer energies, in kWh / h, are presented for each month of the year in the column-type graphs in Figure 2.12, 2.13, 2.14.

$$Q_{cald} = Q_{acm}{}_{oră}^{rez} + Q_{inc}{}_{oră}^{rez} + Q_{vent,inc}{}_{oră}^{rez} + Q_{cald\_teh} \quad \textbf{2.38}$$

$$Q_{frig} = Q_{clim}{}_{oră}^{rez} + Q_{vent,rac}{}_{oră}^{rez} + Q_{frig\_teh} \quad \textbf{2.39}$$

$$W_{el} = W_{acm}{}_{oră}^{rez} + W_{inc}{}_{oră}^{rez} + W_{il}{}_{oră}^{rez} + W_{clim}{}_{oră}^{rez} + W_{vent}{}_{oră}^{rez} + W_{teh} \quad \textbf{2.40}$$

where:
Q_{cald} - hourly heat transfered (kWh/h);
$Q_{acm,oră}^{rez}$ - hourly energy consumption for DHW (kWh/h);
$Q_{inc,oră}^{rez}$ - hourly energy consumption for heating (kWh/h);
$Q_{vent,înc,oră}^{rez}$ - hourly energy consumption for heating - ventilation, (kWh/h);
Q_{cald_teh} - hourly technological heat consumption (kWh/h);
Q_{frig} - hourly cooling transferred energy (kWh/h);
$Q_{clim,oră}^{rez}$ - hourly thermal energy consumption for cooling (kWh/h);
$Q_{vent,rac,oră}^{rez}$ – hourly energy consumption for cooling - ventilation (kWh/h);
Q_{frig_teh} - hourly technological cold consumption (kWh/h);
W_{el} - hourly consumption of transferred electricity (kWh/h);
$W_{acm,oră}^{rez}$ - hourly electricity consumption to operate DHW pump (kWh/h);
$W_{înc,oră}^{rez}$ - hourly consumption of electricity for pumping in heating system (kWh/h);
$W_{il,oră}^{rez}$ - hourly electricity consumption for lighting (kWh/h);
$W_{clim,oră}^{rez}$ - hourly electricity consumption for cooling (kWh/h);
$W_{vent,oră}^{rez}$ - hourly consumption of electricity for fan drive (kWh/h);
W_{teh} - hourly technological electricity consumption (kWh/h);

Figure 2.12 Hourly profiles of heating transferred energy - thermal (monthly average hour), residential

Figure 2.13 Hourly profiles of cooling transferred energy - thermal (monthly average hour), residential

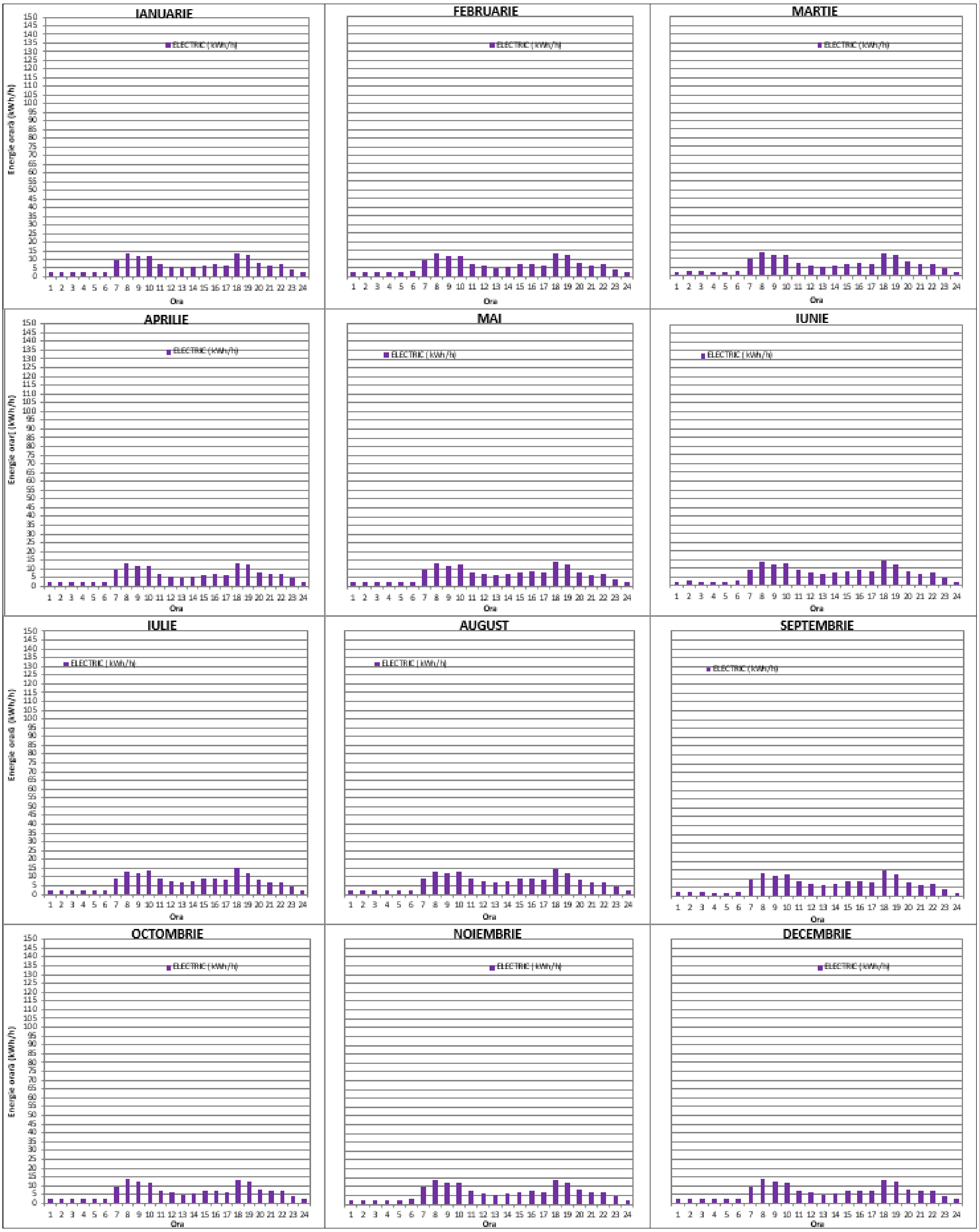

Figure 2.14 Hourly profiles of electricity transferred (monthly average hour), residential

2.4 ENERGY PRODUCED BY THE TRIGENERATION SYSTEM

The basic source of the trigeneration system - the thermal motors - will produce and transfer to the residential consumer 2 types of production energies: electricity and heat.
The heat produced by the thermal motors, Q_{MT}, is divided during the cooling period (in the summer) into the heat required to produce the cooling air for the air conditioning, Q_{Cald}^{R}, in the absorption chiller system and the heat needed to heat and prepare hot water from the water tank warm, Q_{Cald}^{I}.
The electrical energy produced by the electric generators of the thermal motors has two components the auxiliary electricity, E_{aux}, the own consumption from the trigeneration plant and the electrical energy that transforms into voltage transformer, E_{Traf} and is transported to the consumer, W_{el} and to the electrical network (SEN), W_{SEN}.

2.4.1 Calculation of the heat required in absorption chiller

For the elaboration of the energy hour profile the heat required for the chiller has been established the following assumptions: the energy efficiency factor of the chiller is 0.7 and the total installed power of the pumps (solution pump, water pump and purge pump) is 3.7 kW.
The calculation formula corresponding to the heat for the chiller generator is presented in equation 2.41.

$$Q_{cald}^{R} = \frac{Q_{frig} - EER \cdot P_P \cdot \tau}{EER} \qquad \mathbf{2.41}$$

where:
Q_{cald}^{R} - hourly heat energy required in the chiller generator (kWh/h);
Q_{frig} - hourly cooling transferred energy (kWh/h);
EER - energy efficiency ratio of the chiller, 0.7 (-);
P_p – electric power of chiller pumps (mainly the solution pump), 3.7 (kW).
τ – pumps operating time in one hour, 1 (h).

2.4.2 Calculation of the heat required for the hot water tank

For the development of the hourly energy profile, the heat required for the hot water tank - the thermal agent required for DHW preparation and space heating, the following assumptions have been established: heat losses through the tank housing represent 2% of the transferred heat through the tank.
The calculation formula corresponding to the heat required for the hot water tank is presented in equation 2.42.

$$Q_{cald}^{\hat{I}} = \frac{Q_{cald}}{\eta} \qquad \mathbf{2.42}$$

where:
$Q_{cald}^{\hat{I}}$ - hourly heat energy required in the hot water tank (kWh/h);
Q_{cald} - hourly heat transfered (kWh/h);
η – transfer efficiency of the hot water tank, 0.98 (-).

2.4.3 Calculation of the produced heat

The calculation formula corresponding to the elaboration of the hourly profile of thermal energy (heat) produced by the basic source - the thermal engine - is presented in equation 2.43.

$$Q_{MT} = Q_{cald}^{Î} + Q_{cald}^{R} \tag{2.43}$$

where:
Q_{MT} - heat produced by the reciprocating internal combustion engines (kWh/h);
$Q_{cald}^{Î}$ - hourly heat energy required in the hot water tank (kWh/h);
Q_{cald}^{R} - hourly heat energy required in the chiller generator (kWh/h).

Hourly energy profiles, monthly average hours, for the produced thermal energy are shown in Figure 2.15.

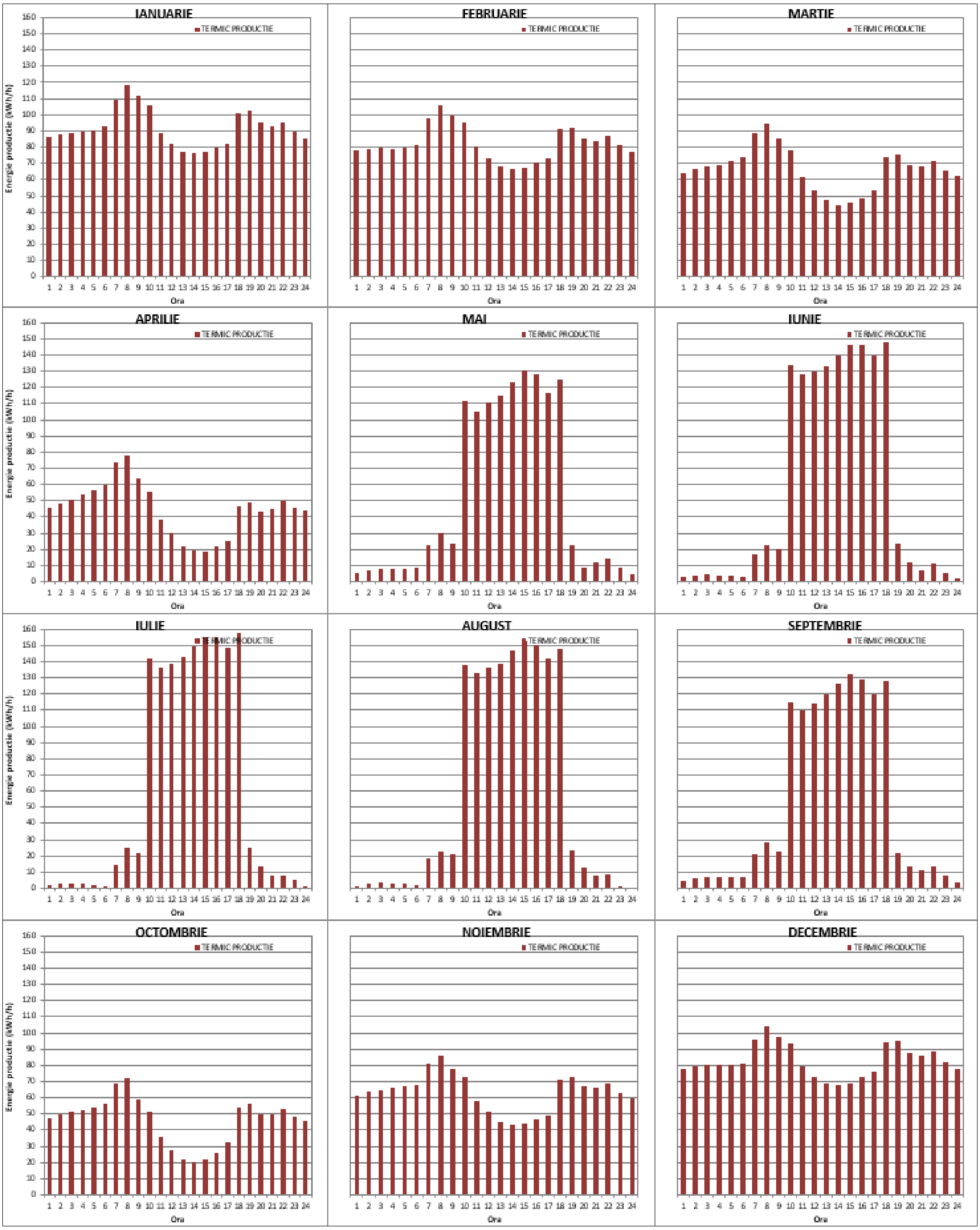

Figure 2.15 Hourly profiles of thermal energy produced (monthly average hour), residential

2.4.4 Calculation of supplied electricity to the grid

For the electricity sold to the National Energy System (SEN), the following hypothesis has been established: the energy sold in the grid is a multiplication by a factor "υ" of the transfer electricity calculated to be necessary for the consumer.
The corresponding calculation formula is presented in equation 2.44.

$$W_{SEN} = \upsilon \cdot W_{el} \qquad \textbf{2.44}$$

W_{SEN} - hourly electricity provided to the grid (kWh/h);
υ – multiplication factor for the delivered energy to the grid, 3 (-);
W_{el} - hourly consumption of transferred electricity (kWh/h).

2.4.5 Calculation of auxiliary electricity

For the electricity consumed internally in the trigeneration plant, it was considered that the electricity consumed in the trigeneration plant (called auxiliary energy) is equal to the sum of the electricity calculated for the circulation pumps of the heating system (chapter 2.2.4), the pumps of the heating system for DHW preparation (ch. 2.2.2) and for chiller pump during the operation.
The corresponding calculation formula is presented in equation 2.45.

$$E_{aux} = W_{acm_{oră}}^{rez} + W_{inc_{oră}}^{rez} + P_p \cdot \tau \qquad \textbf{2.45}$$

where:
E_{aux} - auxiliary energy required by the trigeneration plant (kWh/h);
$W_{acm,oră}^{rez}$ - hourly electricity required to operate DHW pump (kWh/h);
$W_{înc,oră}^{rez}$ - hourly consumption of electricity for pumping in heating system (kWh/h);
P_p - the electric power of the chiller pumps (mainly the solution pump), 3.7 (kW);
τ - chiller's pumps operating time in one hour, 1 (h).

2.4.6 Calculation of the electrical energy of the electrical transformer

In the transformer, for the transport of electricity to consumers, the three-phase energy at 0.4 kV is transformed to a high voltage energy, 20 kV, in order to reduce the voltage losses on the energy transmission. At the consumer, low voltage transformers are mounted and the transported energy is converted back to low voltage electricity, at 0.4 kV, in order to be consumed.
The calculation formula for the transformed energy is presented in equation 2.46.

$$E_{Traf} = W_{SEN} + W_{el} \qquad \textbf{2.46}$$

where:
E_{Traf} - hourly transformed electricity (kWh/h);
W_{SEN} - hourly electricity provided to the grid (kWh/h);
W_{el} - hourly consumption of transferred electricity (kWh/h).

2.4.7 Calculation of total produced electricity

The calculation formula corresponding to the elaboration of the hourly electricity profile produced by the basic source - the thermal engine - is presented in equation 2.47.

$$E_{MT} = E_{Traf} + E_{aux} \qquad \textbf{2.47}$$

Hourly energy profiles, average monthly hours, for the production electricity are shown in Figure 2.16.

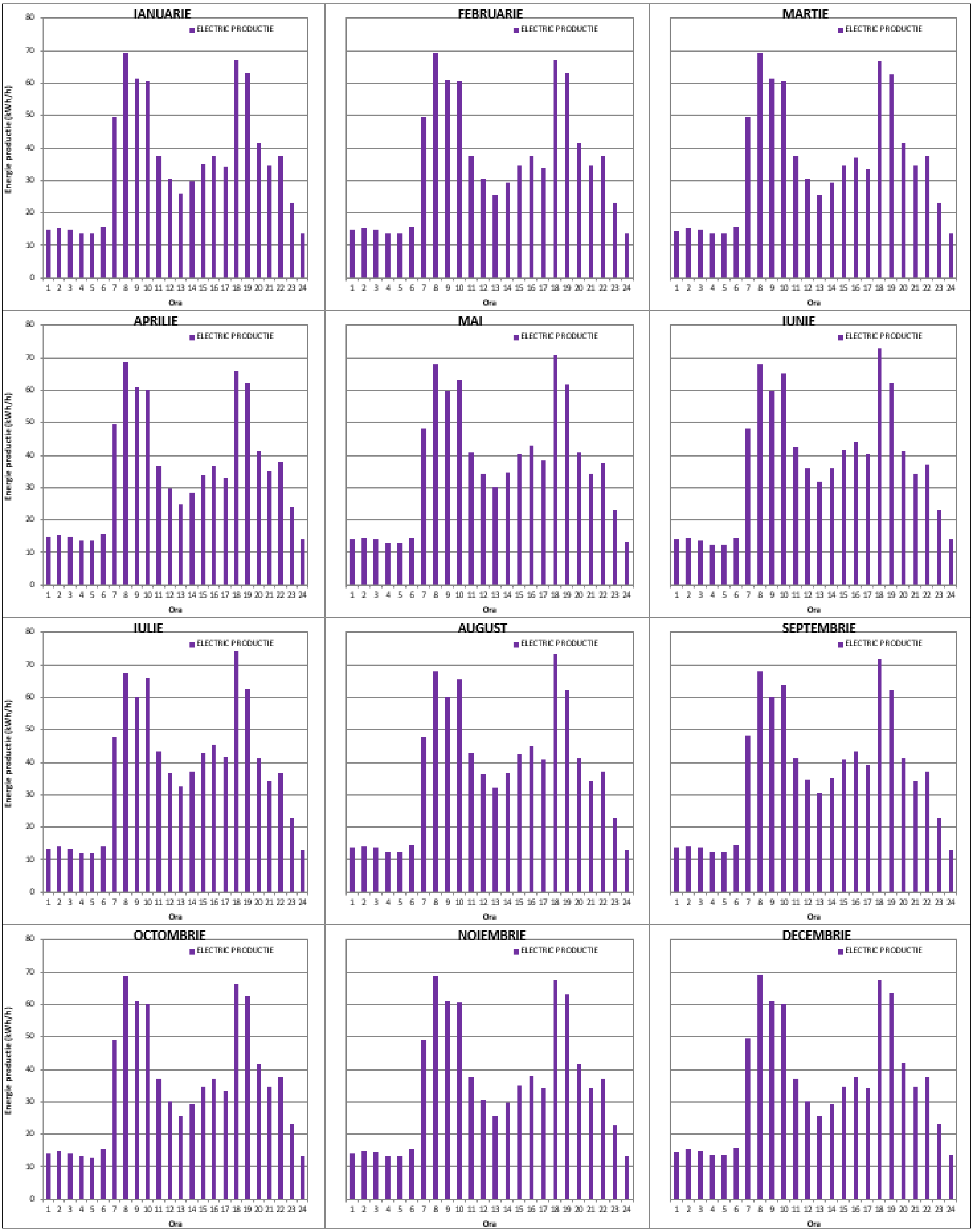

Figure 2.16 Hourly profiles of produced electricity (monthly average hour), residential

2.5 THE PRIMARY ENERGY OF THE TRIGENERATION SYSTEM

2.5.1 Gas energy

For the composition of the hourly energy profile of the fuel - methane gas - consumed by the trigeneration system, the following hypothesis was considered:
η_{TRI}=0.90
where:
η_{TRI} – global efficiency of the trigeneration system.
The formula for calculating fuel energy, methane gas, is presented in equation 2.48.

$$E_{Gaz} = \frac{Q_{MT} + E_{MT}}{\eta_{TRI}} \tag{2.48}$$

2.5.1 Primary energy

The calculation of the primary energy consumed by the trigeneration system is done by multiplying the fuel energy by the conversion factor into primary energy, according to Mc 001, [9].

$$E_p = E_{Gaz} \cdot f_{gn} \tag{2.49}$$

where:
f_{gn}=1.1 – conversion factor for the natural gas into primary energy (-).

Hourly energy profiles, average monthly hours, for input energies: natural gas energy and primary energy are shown in Figure 2.17.

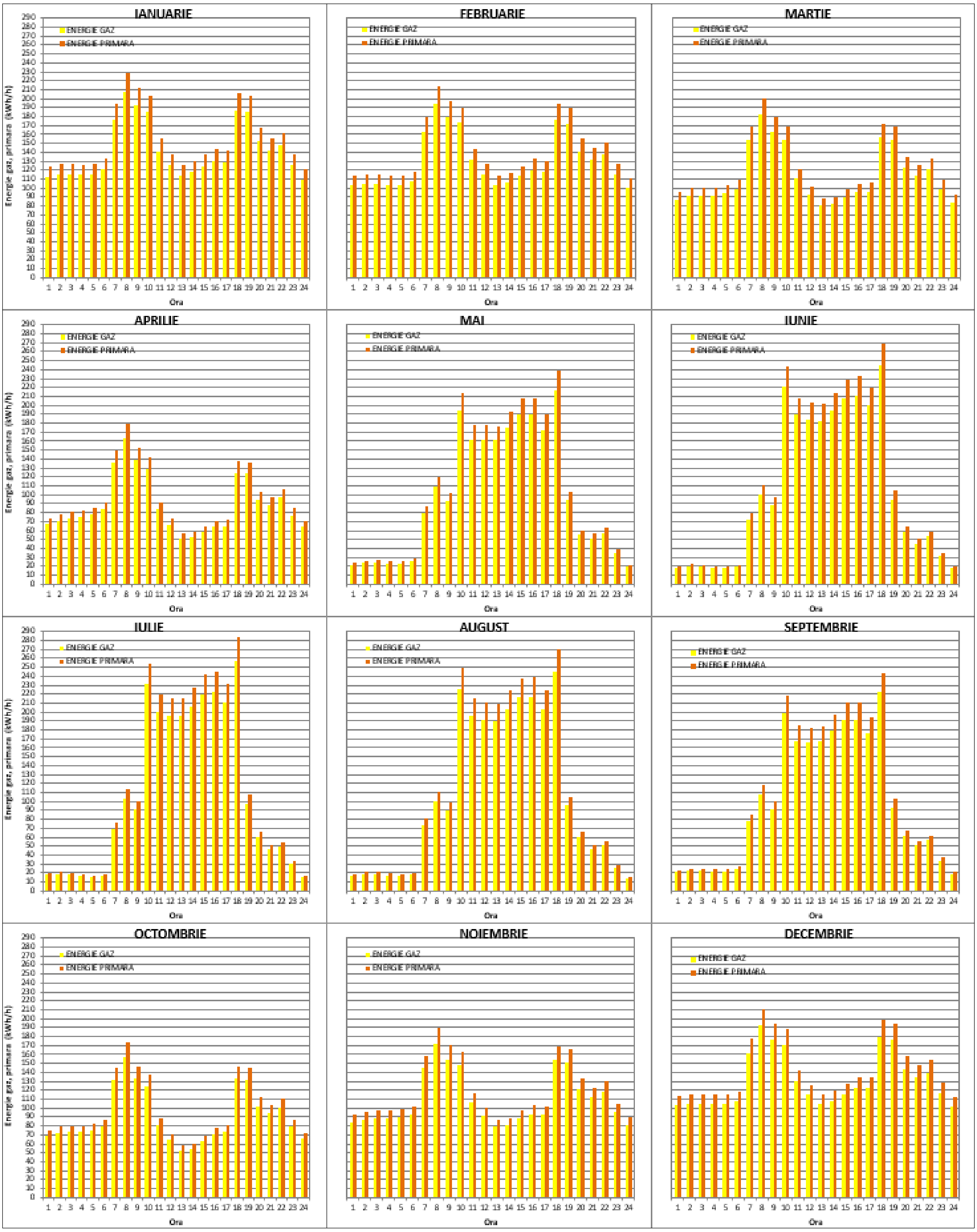

Figure 2.17 Hourly profiles of gas energy and primary energy (monthly average hour), residential

3 REFERENCES

[1] L. A. J. S. E. Fuentes, "A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis," *Renewable and Sustainable Energz Reviews,* no. http://dx.doi.org/10.1016/j.rser.2017.05.229, 2017.

[2] U. U. C. N. U. G. A. I. U. T. U. T. B. I. B. UTCB, "Partea II-3, Performanţa energetică a instalaţiilor din clădiri," in *Metodologie de calcul al performanţei energetice a clădirilor*, Bucureşti, MDRAP, 2006, pp. Partea II-3 apa caldă.

[3] "Enciclopedie Tehnică de Instalaţii," in *Manualul de Instalaţii, Instalaţii de Încălzire*, Bucureşti, ARTECNO, 2010, p. 66.

[4] U. U. C. N. U. G. A. I. U. T. U. T. B. I. B. UTCB, "Partea II-1, Performanţa energetică a instalaţiilor din clădiri," in *Metodologia de calcul al performanţei energetice a clădirilor*, Bucureşti, MDRAP, 2006, pp. Partea II-1 încălziri.

[5] "https://www.e-distributie.com," Enel, Operator de reţea Muntenia, [Online]. Available: https://www.e-distributie.com/ro-RO/Pagini/muntenia.aspx. [Accessed 16 03 2019].

[6] A. D. I. C. D. Enache, "Îndrumător de proiectare vol. I," in *Instalaţii de Ventilare şi Climatizare*, Bucureşti, MATRIX ROM, 2005.

[7] U. U. C. N. U. G. A. I. U. T. U. T. B. I. B. UTCB, "Partea II-2, Performanţa energetică a instalaţiilor din clădiri," in *Metodologie de calcul al performanţei energetice a clădirilor*, Bucureşti, MDRAP, 2006, pp. Partea II-2 ventilaţii.

[8] V. I. Iolanda Colda, Writer, *Consum energetic al instalațiilor de ventilare.* [Performance]. FII_UTCB, 2013.

[9] G. Tausan, "Cap. 2 Noțiuni aer uscat umed .pdf," [Online]. Available: https://www.academia.edu/.../CAP_2_NOTIUNI_AER_USCAT_SI_UMED_def.pdf. [Accessed 07 iulie 2019].

[10] C. P. M. G. P. N. Negurescu, Motoare cu aprindere internă, Procese, București: Matrix Rom, 1996.

[11] V. I. F. I. A. I. G. Mărcuş, "Energy analysis of a CHP plant with internal combustion engines, for a district heating system, based on the information from the annual database," in *1st Conference of the UTCB Doctoral School*, Bucureşti, 2018.

[12] C. I. L. G. Mărcuş, "Partial load efficiency analysis of a CCHP plant with RICE and H2O-LiBr absorption chiller," in *REHVA 13th HVAC World Congress CLIMA 2019*, Bucharest, 2019.

[13] V. I. R. F. F. I. G. Mărcuş, "Efficiency analysis of a CHP plant, based on reciprocating engines as prime movers and a hot water boiler as peak source," *RRIC,* vol. 9, no. 3, pp. 278-291, 2018.

[14] Natural Resources Canada, "RETScreen Expert (free version) download for PC," 19 September 2016. [Online]. Available: https://en.freedownloadmanager.org/.../RETScreen-Expert.ht.... [Accessed 26 February 2019].

[15] L. D. I. C. R. D. T. C. G. B. T. M. L. D. j. A. R. D. T. M. S. V. P. V. V. V. V. Şt. Vintilă, "Enciclopedie Tehnică de Instalaţii," in *Manualul de Instalaţii, Instalaţii Sanitare*, Bucureşti, ARTECNO, 2010, p. 46.

[16] Ț. S. M. U. L. FRUNZULICĂ Rodica, "Modalitatea optima si exemplu de selectie a solutiei de

cogenerare de mica putere pentru consumatorii de tip condominiu," in *Conferinta Eficienta, confort, conservarea energiei si protectia mediului (editia a XIV-a*, București, 2010.

[17] R. H. System, "http://www.calor.ro/documents/products/32660/Cazane%20fonta%20Rima%20RS%20-%20Manual%20date%20tehnice%20limba%20engleza.pdf," Rima Heating Systems. [Online]. [Accessed 08 IUNIE 2019].

[18] M. Engines, "https://www.engines.man.eu/man/.../Power_Gas_EN_150927...," MAN Engines. [Online]. [Accessed 08 iunie 2019].

[19] C. SANYO, "acare.eu/CarrierCD/Litt/11615_PSD_11_05.pdf," CARRIER SANYO. [Online]. [Accessed 15 DECEMBRIE 2018].

[20] "Enciclopedie Tehnică de Instalații," in *Manualul de Instalații - Instalații de Ventilare și Climatizare*, București, ARTECNO, 2010, p. 14.