

Prediction of consumed electricity in residential spaces

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Abstract: This report presents an approach for predicting energy consumption in a specific living space based on experimental data on the indoor microclimate. The data for the analysis of the temperature in the room and the external temperature of the environment is used for the period from 01.01.2016. until 31.12.2023, and a period of 18:00 - 24:00. Regression analysis is used to create a model for increasing energy consumption.

Keywords: PREDICTING, ENERGY CONSUMPTION, REGRESSION ANALYSIS, LIVING SPACE, TEMPERATURE MODEL

1. Introduction

This study aims to propose a method for forecasting the required electricity for heating a predefined and defined residential area. For the purposes of the research, regression analysis is used based on data obtained through the measurement of temperature characteristics related to the desired comfortable living conditions in the space. The parameters of the residential space and the values for air temperature and humidity were measured during different periods of the day, as well as across the four seasons and several consecutive years - from the beginning of 2016 to the end of 2023. The measurements reflect the "state of affairs as they are," i.e., data on the environment, temperature, humidity, and the amount of electricity consumed according to (and solely based on) the subjective comfort perception of the tenants while minimizing costs. The measured data and the results of their analysis and processing will be used to constructively improve the environment and/or undertake measures to minimize current expenses. This report, in a sense, serves as a continuation and enhancement of another report by the author [1].

2. Conditions of the experimental measurement

In Fig.1 and Fig.2 the dimensions and location of the living space are presented - in practice, one room of an apartment in a residential building.

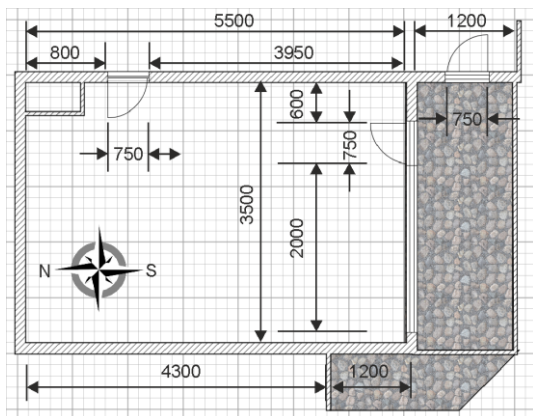


Fig. 1 Living space dimensions [mm].

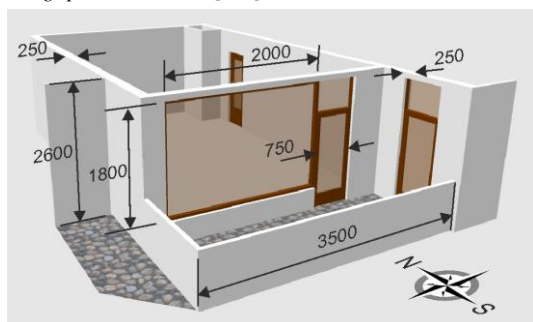


Fig. 2 3D model of living space [mm].

All doors and windows are of the energy-saving type – corresponding PVC and solid wood, the walls are built of bricks and are

250 mm thick. The glazing of the exterior doors and windows is made of double 4 mm ordinary glass. The floor is insulated with extruded polystyrene XPS Fibran 20 mm and cement plaster, on top of which 8mm thick laminated flooring is placed. The ceiling is of the "suspended" type with installed mineral wool insulation with a thickness of 80 mm. The walls are plastered and painted with latex - they are not insulated, but the apartment has no external walls and all the neighbouring apartments are occupied by tenants.

The following parameters are measured:

- internal temperature;
- external temperature;
- atmospheric pressure;
- indoor and outdoor air humidity;
- wind speed and direction;
- current precipitation and cumulative values.
- electricity consumption.

A weather station OPUS TFA 35.1112 IT, presented in Fig.3, is used to measure the above [2].



Fig. 3 Weather station OPUS TFA 35.1112 IT.[2]

Table 1: Technical specifications of OPUS TFA 35.1112 IT.

Technical specification	Value
Type	Weather station
Temperature measurement (OUT)	Yes
The range of temperature	-40° C - + 60° C
Additional features	The weather forecast, preservation temperature, clock, alarm clock, regular calendar
Moisture measurement	In/outdoors, in the range of 1-99%
Wind characteristics	Speed, direction
Remote sensor	Wireless (range 100 m)
Data transfer	Transmission frequency 868 MHz
Power supply	Autonomous, battery LR14

Technical specification	Value
	(included), display of battery level
Displaying information	Numbers and symbols, the choice of measurement units
Sound indication	Yes
USB interface	Yes

For the purposes of the study, it is accepted:

• the day is divided into 4 periods: 00:00-06:00, 06:00-08:00, 08:00-18:00, and 18:00-24:00, the reason for this division is as follows:

- 00:00-06:00 – rest time, heating devices are not working in the room, a lower temperature is required;
- 06:00-08:00 – the room needs a comfortable temperature, after 08:00 there are no people in the room;
- 08:00-18:00 – day mode, there are no people present in the room and the heating devices are not working;
- 18:00-24:00 – evening mode - comfortable conditions are necessary, and heating, air conditioning and lighting devices are usually turned on.

The annual cycle is divided into 4 quarters as follows:

- 01 January – 31 March – Winter;
- 01 April – 30 June – Spring;
- 01 July – 30 September – Summer;
- 01 October – 31 December – Autumn.

For the purpose of this study, the above division of the annual cycle does not contradict the astronomical seasons, due to the visible observation of a shift in the real climatic conditions, for example, spring is "late", it is cold and humid, the real summer "comes later", the autumns are long and warm. The adoption of this condition is also convenient from the point of view of the monthly accounting of the consumed electricity. The created temperature model of the room presents:

- average value of the temperature in the room by months (seasons) and years in the defined time intervals; [1]

The tenants' lifestyle (during the period from 18:00 to 24:00) is not associated with cooking in the room and/or other activities that typically require high electricity consumption. For the cited period of the day, electricity is used for heating (climate control) and other relatively small energy needs, such as lighting, periodic use of laptops and charging mobile phones. The latter do not have a significant impact and are thus disregarded in this context. Since the beginning of 2024, the consumption of heating devices is measured exclusively using the eMylo Smart WiFi Energy Meter (Fig.4), which allows for the collection of accurate data.



Fig. 4 eMylo Smart WiFi Energy Meter.[3]

3. Obtained results

The data from the measurements regarding the average monthly temperatures for the period from Jan 1, 2016, to Dec 31, 2022, are shown in Table 1. The following values are distinguishable:

- Average monthly indoor temperatures – InTemp;
- Average monthly outdoor temperatures – OutTemp;
- Average daily electricity consumption – Day;
- Average nightly electricity consumption – Night;
- Average monthly total electricity consumption – All.

Table 1: Data on average monthly temperatures in the room, the environment (for the period 18:00-24:00), and average monthly electricity consumption for the period January 1, 2016 – December 31, 2022.

Month	Period - 01.01.2016 - 31.12.2022				
	InTemp	OutTemp	Day	Night	All
1	22,42	2,38	556	128	684
2	22,50	6,50	458	128	586
3	22,35	8,92	378	82	460
4	23,17	15,20	330	83	413
5	24,11	19,53	290	89	379
6	25,88	24,49	241	81	322
7	27,55	27,12	210	61	271
8	28,04	28,28	271	58	329
9	26,49	23,76	267	76	344
10	23,65	17,10	253	76	329
11	22,84	9,72	336	77	413
12	23,00	4,98	499	112	611

From the table, it is clear that the measured values for indoor temperature (InTemp) fall within the range of so-called "comfortable living conditions" [4]. This is also reflected in the electricity consumption across different seasons - for the months of June to August, electricity consumption is the lowest, while for the months of December to January, consumption is the highest. Specifically for the period from 18:00 to 24:00 hours by year, the data are presented in Table 2:

Table 2: Average Temperature (Ave InTemp), Average air humidity (Ave InHum) and their standard deviations (respectively StdDev InTemp and StdDev InHum) for 2016-2022 (18:00-24:00)[1].

Year	Ave InTemp	Ave InHum	StdDev InTemp	StdDev InHum
2016	24,3	51	2,6	6
2017	23,8	50	2,8	6
2018	24,0	51	2,6	6
2019	24,4	51	2,5	7
2020	24,7	51	2,3	6
2021	24,7	51	2,7	7
2022	25,0	51	2,2	5
Average:	24,4	50,8	2,5	6,3

The sensor for measuring the internal air temperature is placed at a height of 1.5m from the floor of the room, on an internal wall and more than 3.0m from the door leading to the outside space. The sensor to measure external air temperature is installed in a container that excludes direct sunlight and the temperature effect of air flows. All measurements were taken under identical conditions, with the weather station's functional components remaining stationary.

The data analysis was performed using regression analysis, with two software products used for result verification, as follows:

- MatLab – <https://www.mathworks.com/> [5]
- Orange - <https://orangedatamining.com/> [6]

Regression analysis can be used to examine phenomena for which a certain number of observations are known. Each observation has two or more characteristics. Following the assumption that at least one of the characteristics depends on the others, a relationship between them is established... that is, a function is found that sufficiently well matches some characteristics or variables with others. In the general case, when we have one or more independent variables that are not labeled, but we have their realizations, the goal is to determine (almost) completely the coefficients of a function of the type (for multiple linear regression):

$$Y = A_1x_1 + A_2x_2 + A_3x_3 + \dots + A_nx_n;$$

... thus creating a model of the interaction between them. The state of Y depends on the quantities X_1, X_2, \dots, X_n – they are independent, but the high correlation between the quantities does not necessarily imply a causal relationship between them.

In fact, linear (multiple) regression, as a toolkit, determines the coefficients A_1, A_2, \dots, A_n , and then it is possible to predict future (probabilistically forecasted) values of Y with a set of input data for x_1, x_2, \dots, x_n or to restore lost (missing, undelivered) data for independent variables based on known values of Y.

In this specific case, we have the variable Y – consumed electricity, and two variables x_1 and x_2 – respectively indoor (for the room) and outdoor temperature (of the environment). The results of the study conducted with MatLab and Orange are presented in Fig.5 and Fig.6.

Step 1. Input Datas.

```
evndatas = readtable('datas.xlsx','ReadRowNames',true);
```

Step 2. Model and Result.

```
evnmodelspec = 'ALLEVN ~ InTemp + OutTemp';
mdl = fitlm(evndatas,evnmodelspec)
```

mdl =
Linear regression model:
ALLEVN ~ 1 + InTemp + OutTemp

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	-354.14	347.51	-1.0191	0.33478
InTemp	47.049	16.488	2.8536	0.018978
OutTemp	-23.144	3.7909	-6.1051	0.00017815

Fig. 5 Regression analysis with MatLab program.

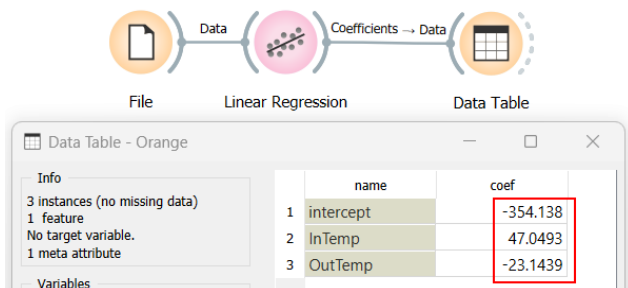


Fig. 6 Regression analysis with Orange program.

Received results (Fig. 5 and Fig. 6) are identical, and the sought model of consumed electricity for the period takes the form:

$$Y = -354 + 47x_1 - 23,144x_2 \quad (1)$$

Expression (1) can be used to forecast future electricity consumption or to fill in missing data for surveyed (or future) periods. We also have data for consumed electricity for 2023, and we will use the same for verifying the accuracy of the model.

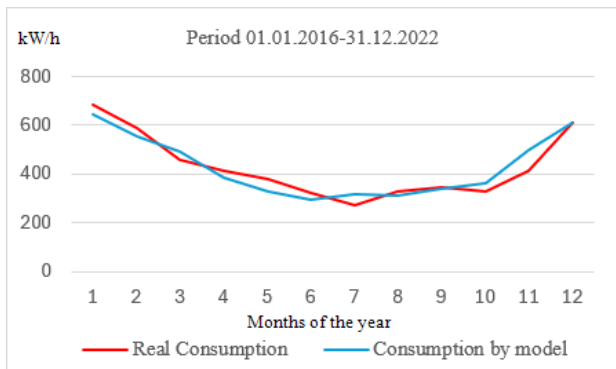


Fig.7 Model (1) conformity for the testing period.

Fig. 7 and Fig. 8 illustrate how expression (1) relates to the actually measured data for the period from 01.01.2016 to 31.12.2022 and for the period from 01.01.2023 to 31.12.2023.

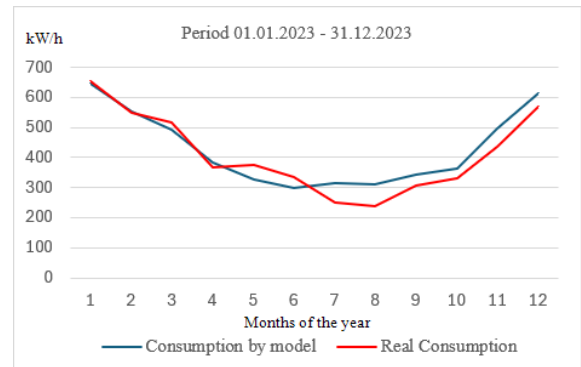


Fig. 8 Correspondence of model (1) to data for 2023.

A "critical reading" of the energy consumption data would suggest that this is the electricity consumed for the entire apartment, but it should be remembered that: (i) the people living in the apartment are two tenants with established habits of food (outside the home), (ii) they spend all (almost, all others are negligibly few) weekends away from home, (iii) expenses for lighting, electricity, water for heating are a constant amount and the main consumption is related to heating the premises during the winter period and cooling the premises during the hot days.

All measured data are reliable because, in the last 2 years, parallel measurements have been made with another weather station Weather Screen PRO DNT000008 [7], sensors for measuring air purity, solar radiation and lightning detector within a radius of 40km have been added to it. The measured data are uploaded to the Internet at: <http://www.ecowitt.net>.

3. Conclusions

The recommended levels of air humidity (according to Regulation No. RD-07-3 [4] and the American Association ASHRAE [8]) are 40%–60%, and the optimal temperature levels for cold and warm periods are 20–23°C and 22–25°C, which are defined and permissible limit values. During the target periods (18:00–24:00) optimal values of temperature and air humidity are maintained.

The proposed approach for forecasting the required electricity consumption is suitable for the temperature partitioning (1) of the room. The study will also be conducted under conditions considering the energy consumption for each individual activity of the building's tenants (for each separate circuit of the electrical installation).

The data show that the costs incurred for thermal insulation are justified and at this stage, there are no better solutions on the market, except for a more modern type of glazing for external doors and windows.

4. References

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