Analysis of the electric loads of residential and public buildings in urban power supply systems

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Abstract. Accurate determination of the calculated electric loads is a basis for power supply systems design. Values of the calculated loads influence parameters of the electrical grid. That is why the values of the calculated loads should not be exceeded in operation. Calculated electric loads also influence investments in the designed grid. For the most effective usage of the investments, the values of the calculated loads should not be overstated or understated. This article is about the applicability of the problem of the elaboration existing databases used in governing documents. Based on the obtained data, the analysis of the calculated electric loads of public buildings is carried out. Typical daily load graphs at the input of the apartment houses with electric stoves are given. Accurate load graphs at the input of the apartment houses are received, according to the results of measurements for various days of the week. The received load graphs are compared with given graphs from technical literature. We have found that the configuration of the up-dated load graphs of residential buildings significantly differs from the given graphs.

1. Introduction
Nowadays, the questions of the research and calculations of the electric loads of residential and public buildings obtain special applicability. There is a great change in people’s lifestyle and social standard of living. There has been an intense growth of the cities and urban population. In the last couple of years, energy efficiency and savings have become a key problem due to an increase in energy consumption, an increase in energy prices and concerns about the environmental changes [1]. Prediction of electricity consumption is very important for electricity traders to balance their electricity purchase and sales portfolio [2].

The problem of reliably determining the electric loads of residential and public buildings in large cities is of difficulty. The residential sector accounts for a substantial percentage of total electricity consumption. Modelling residential electricity consumption is a complex task due to the large variety of variables involved and occupant behaviour [3]. It is not possible to accurately determine the load consumed at this moment by electrical receivers.

For the last decades, the content and the structure of electrical receivers in residential and public buildings has profoundly changed. It has become the reason of energy consumption change [4]. The number of microprocessing devices and household appliances, which are used not only in households but in public buildings, has increased. That is why the elaboration of calculated electric loads of residential and public building is required [5,6].

Earlier, study guides about power engineering had been rewritten, but in the last years, there were no changes in these reference materials. For the last period of twenty years, there has been scientific and technological progress worldwide. These changes are not rebound in most reference materials.
In this article, load graphs are plotted according to data at the input of residential buildings and compared with typical load graphs from reference literature. The comparative analysis of plotted and typical graphs is carried out.

The analysis of the results of electric loads on the first level of power supply systems is carried out for public buildings. These electric loads are obtained based on existing methods outlined in current governing documents (Set of Rules 256.1325800.2016 and Guidance Document 34.20.185-94).

2. Basic data

2.1. Data for residential buildings

A study object is a typical panel 17-storey residential house with 471 flats and electric stoves. We have taken as basic data the actual results of measurements by an automated system of control and metering of energy resources (ASCME) at the input of the building. The load has been recorded continuously every 30 minutes from an electric energy counter.

2.2. Data for public buildings

For the electric load calculation, we have taken three different public buildings, where electric loads most probably would differ from each other.

Basic data for each public building are the amount and types of electrical appliances, their nominal rate and power factor, which are reported in the equipment passport. The number of electrical appliances reaches hundreds or even thousands. That is why it is combined into appointments groups. For each group, installed power is mentioned.

Table 1. The number and installed power of electrical appliances in music school

| №  | Name of group of electrical appliances                  | Amount | Installed power $P_n$, kW | Power factor $\cos \phi$ |
|----|-------------------------------------------------------|--------|--------------------------|-------------------------|
| 1  | Primary lighting                                     | 2136   | 43.6                     | 0.96                    |
| 2  | Emergency lighting                                   | 624    | 13.3                     | 0.96                    |
| 3  | Facade lighting                                      | 184    | 10.2                     | 0.90                    |
| 4  | Food unit equipment                                  | over 5 | 94.7                     | 0.87                    |
| 5  | Workrooms (Lathes and other)                         | over 5 | 25.4                     | 0.67                    |
| 6  | Computers and other devices                          | over 5 | 84.9                     | 0.80                    |
| 7  | Music hall                                           | over 30| 79.9                     | 0.93                    |
| 8  | Multimedia systems in classrooms                     | over 20| 17.8                     | 0.86                    |
| 9  | Electric hand dryer                                  | over 5 | 40.0                     | 0.98                    |
| 10 | Ventilation                                          | 9      | 64.9                     | 0.83                    |
| 11 | Pump unit                                            | 5      | 13.4                     | 0.87                    |
| 12 | Roof drain with electrical heating                   | over 30| 1.0                      | 0.75                    |
| 13 | Air conditioning                                     | 117    | 272.0                    | 0.84                    |
| 14 | Heating and air curtain                             | 5      | 25.1                     | 0.98                    |
| 15 | Steam humidifiers                                    | 8      | 234.8                    | 0.98                    |
| 16 | Elevator                                             | 3      | 24.8                     | 0.65                    |
| 17 | Individual heating plant                             | 6      | 28.7                     | 0.93                    |
| 18 | Weak-current systems                                | over 30| 33.2                     | 0.75                    |
| 19 | Fire retardant valve                                | over 20| 2.3                      | 0.75                    |
| 20 | Evacuation lighting                                 | 180    | 3.8                      | 0.96                    |
| 21 | Fire extinguishing unit                              | 1      | 5.5                      | 0.85                    |
| 22 | Fire signal system                                  | over 50| 3.6                      | 0.75                    |
| 23 | Smoke ventilation                                    | over 5 | 228.4                    | 0.85                    |

3. Comparative analysis of plotted graphs of residential buildings with typical graphs

In technical literature, for example [7], typical graphs and their main factors are given for consumer groups, such as apartment buildings with gas and electric stoves, canteens, and supermarkets and others. In [8] typical load graph of a consumer of residential city areas is given. A daily load graph of
a residential building with electric stoves is given in reference material [9]. Working days and weekends are already separated in this graph. A graph with separated load curves of Saturday and Sunday is given in [10].

3.1 Workdays graphs
Comparing plotted graphs of workdays with different averaging intervals (Figure 1), you can see, that with interval increasing morning and day peaks and off-peaks load disappear. In Figure 1: a curve 1 is a graph with a half-hour averaging interval; a curve 2 is a graph with a one-hour averaging interval; a curve 3 is a graph with a two-hour averaging interval. Electric load increases after night off-peak until the evening peak in curve 3 compared to the curve 1. In the curve 3, not all specific points and periods of the daily load graph are reflected. The plotted graph with a half-hour averaging interval and the graphs from [9] and [10], are presented in Figure 2. A daily winter graph with a one-hour averaging interval is presented in [7]. It is compared with a plotted graph in Figure 3. The graphs with a two-hour averaging interval are presented in Figure 4. Hereunder a comparative analysis of these graphs is given.

You can see a night minimum load in Figures 2-4. But off-peaks load in the graphs with a half-hour and one-hour averaging intervals last less than in the graphs from the reference materials. But in Figure 4, the off-peak load lasts two hours longer, than in the graph from [8].

A load minimum in the plotted graphs outreaches the minimal load in compared graphs from the reference materials nearly 3.5 times. Such a big load difference is because the graphs from [7-10] were plotted before 1990 when only the fridge could consume the energy at night. The energy night consumption growth is bound by the increase in the number of electronic devices, which people leave for charging for the night. Some people prefer to leave their computers in sleep mode, also consuming energy. In the last decade, people started actively use electronic devices with timer and delayed start mode. Today you should not be near the device to turn on a cooking program or to turn on a washing machine. If you have a two-part tariff, you can save your money by placing the devices in night work mode.

In the plotted graph, in Figure 2, you can see a morning maximum taking place from 7.30 to 8 a.m. In typical graphs from [9] and [10] (Figure 2) the morning maximum is much lower and lasts from 7 to 7.30 a.m. In the graph from [7] (Figure 3), the morning maximum starts later and lasts much longer. And in the plotted graph with a two-hour averaging interval (Figure 4) there is no morning maximum at all. In the graph from [8], you can see a standard morning maximum for typical daily graphs, which lasts from 10 to 12 a.m.

Nowadays, people use electric kettles, coffee brewers, toasters, blenders, and other electrical devices to cook breakfast in the morning. To have a clean look, people use hairdryers and curlers before work or study. All these devices increase the morning maximum. In [9] and [10], you can see a large electric load decrease after the morning maximum, besides in the plotted graph (Figure 2) the decrease is less sharp.

Nowadays, people start to wake up at 6 a.m. They leave their houses in a different time, that is why there is no off-peak load after the morning maximum. In the graph from [9] (Figure 2), you can see the second-morning maximum. However, in the graph from [10], from 9.30 to 10 a.m., you can see the load increase. From 10 to 10.30 a.m. there is the second-morning maximum.

In the plotted graphs you can see a small day off-peak load only in the graph with a half-hour averaging interval. There is a day off-peak load from 2 to 4 p.m. in the graph from [8] (Figure 4). But in the plotted one, the load is increasing at that time. It is because people continue to use electronic devices after lunch.

The evening maximum in the graphs from [9] and [10] lasts from 6.30 to 7 p.m. But in the plotted with a half-hour averaging interval it is from 7.30 to 8 p.m. The evening maximum in the plotted graph with an hour averaging interval lasts from 7 to 8 p.m. But it lasts from 6 to 8 p.m. in the graph from [7]. Nowadays, people come home later because they often stay behind after hours and spend more time on the way home.
The new load graphs become more even and fill up. Mainly, the plotted workdays graphs quite differ from the typical graphs from [7-10].

![Figure 1](image1.png) **Figure 1.** Daily workdays load graphs of the residential building with electric stoves with an averaging interval (1 – for 30 minutes; 2 – for 1 hour; 3 – for 2 hours)

![Figure 2](image2.png) **Figure 2.** Daily workdays load graphs with a half-hour averaging interval (1 – plotted; 2 – from [9]; 3 – from [10])

![Figure 3](image3.png) **Figure 3.** Daily workdays load graphs with a one-hour averaging interval (1 – plotted; 2 – from [7])

![Figure 4](image4.png) **Figure 4.** Daily workdays load graphs with a two-hour averaging interval (1 – plotted; 2 – from [8])

### 3.2. Saturday electric load graphs

Electric load graphs with a half-hour averaging interval (a plotted Saturday graph, a Saturday graph from [10], and weekend graph from [9]) are compared in Figure 5.

The character of the differences between the Saturday graphs at nighttime is the same as for the workdays graphs.

You can see the morning maximum in the graphs from [9] and [10] from 10 to 10.30 a.m. The daily maximum of electric load also takes place in this time in the graph from [9]. Electric load in the graph from [10] is also high at the time, which is unusual for the typical daily workdays graph.

### 3.3 Sunday electric load graphs

Electric load graphs with a half-hour averaging interval (a plotted Sunday graph, a Sunday graph from [10], and weekend graph from [9]) are compared in Figure 6.

There is not a strongly marked morning maximum in the plotted graph as contrasted with the graphs from [9] and [10]. The character of the differences between the Sunday graphs in the morning and daytime is the same as for the Saturday graphs.
The evening maximum in the plotted graph and the graph from [10] lasts from 6.30 to 7 p.m. The evening maximum in the graph from [9] lasts from 6.30 to 8 p.m. It has become smoother as for Saturday graph.

![Figure 5. Daily Saturday load graphs with a half-hour averaging interval (1 – plotted; 2 – from [9]; 3 – from [10])]

![Figure 6. Daily Sunday graphs load with a half-hour averaging interval (1 – plotted; 2 – from [9]; 3 – from [10])]

4. Calculation of the electric loads of public buildings

4.1. Calculations of the electric loads according to Set of Rules 256.1325800.2016

A method of the calculations is that electrical appliances are divided into groups according to their operation mode and function. According to the tables in Set of Rules 256.1325800.2016 (SoR 256) for public buildings, reduction demand factors are determined for each group. Further, the maximum load mode should be determined. Then the maximum current in operating mode is calculated for the cables at the input of the building. But there are some contradictions when determining demand factors, which cannot be solved unambiguously.

Calculated electric load of the group of electrical appliances is defined by Formula 1:

\[ P_{c} = K_{d} \cdot P_{I} \]  \hspace{1cm} (1)

where \( K_{d} \) is a demand factor; \( P_{I} \) is an installed power of the group of electrical appliances (see Table 1), kW.

Calculated electric load of the feed lines in operating and emergency modes, with lighting and power appliances feeding together, is determined by Formula 2:

\[ P_{c,2} = K \cdot \left( P_{c,1} + P_{c,p} + K_{1} P_{c,r,e} \right) \]  \hspace{1cm} (2)

where \( K \) is a factor, which defines a mismatch of calculated maximum loads of power and lighting appliances, taken according to table 7.11 from [11];

\( K_{1} \) is a factor, depending on the ratio of the calculated lighting load and calculated refrigeration equipment, taken according to the appendix 3 to table 7.11 [11];

\( P_{c,1} \) is a calculated electric lighting load, kW;

\( P_{c,p} \) is a calculated electric power appliances load (without refrigeration equipment load), kW;

\( P_{c,r,e} \) is calculated electric refrigeration equipment load, kW.

Reduction demand factors \( K \) and \( K_{1} \) are determined by the ratio of the lighting load and power appliances load and refrigeration equipment load, respectively.

Further, the maximum load mode should be determined to choose a cable cross-section at the input of the building. In this case, the loads in winter and summer modes are calculated. Then the maximum load is picked.
Power factor is taken according to table 7.12 [11]. The apparent power of the feed lines is calculated by Formula 3:

$$S_\Sigma = \frac{P_{\text{e}}} {\cos \phi}$$  \hfill (3)

Maximum calculated current at the input of the building is calculated by Formula 4:

$$I_c = \frac{S_\Sigma}{\sqrt{3} \cdot U}$$  \hfill (4)

where $U$ is a voltage of the three-phase electric mains, kV.

4.2. Calculations of the electric loads according to Guidance Document 34.20.185-94

Calculations of electric loads by the method of specific loads are carried out according to Guidance Document 34.20.185-94 (GD 34). Specific load of a public building is taken from table 2.2.1 [12] and multiplies by quantitative measure. Calculated electric load of feed lines is determined by Formula 5:

$$P_{\text{e} \Sigma} = P_{\text{e} \text{m}} \cdot n$$  \hfill (5)

where $P_{\text{e} \text{m}}$ is a specific load, kW/quantitative measure; $n$ is a number of students (for music school).

Power factors are given in table 2.2.1 [12], therefore, apparent power is determined by Formula 3. Maximum calculated current at the input of the building is calculated by Formula 4.

5. Analysis of the results of calculated loads of public buildings

Apparent power and calculated electric current data, which are calculated by the demand factor method (SoR 256) and by the method of specific loads (GD 34), are shown in Table 2.

Both methods are approximate, so we recommend using them for sample calculation at the design task stage. But these methods are widely used in urban electric grids design due to their simplicity.

It is not possible to identify a general tendency of underestimating or overestimating the apparent power, calculated by the first method, compared to the second method. Calculated load for a music school by GD 34 is 1135% less than the load by SoR 256. For a design organization, the difference between the electric loads is 63.0%. For a grocery store, the load by GD 34 is 60.4% more.

The divergence of the results of calculated loads for the music school reaches enormous values. It is assumed, that specific loads for schools from GD 34 do not consider the air conditioning system load because earlier these systems were not as widespread in educational institutions as nowadays. Neglection of other systems is also possible because a lot of microprocessing devices appeared in public buildings since that time.

For the design organization as for the music school, you can see the overestimation of electric load calculated by SoR 256, compared to the second method.

| № | Building         | SoR 256.1325800.2016 | GD 34.20.185-95 | The difference between the apparent powers, % |
|---|------------------|----------------------|-----------------|-----------------------------------------------|
|   |                  | $S_\Sigma$, kW        | $I_c$, A         | $S_\Sigma$, kW        | $I_c$, A         |                                                     |
| 1 | Music school     | 487.9                | 741.3           | 39.5                      | 60.0            | 1135                                           |
| 2 | Grocery store    | 146.1                | 222.0           | 234.4                      | 356.1            | 60.4                                           |
| 3 | Design organization | 212.4               | 322.7           | 130.3                      | 198.0            | 63.0                                           |

For the grocery store, electric load by GD 34 contrariwise overestimate the load value calculated by SoR 256. It is supposed, the electric equipment is more power-efficient than the equipment used decades ago. Modern refrigerating equipment can save low temperature inside the chamber, which makes it more efficient.
6. Conclusion
Based on the results of the study, the following main conclusions were obtained for residential and public buildings.
It was revealed for residential buildings, that the minimum load of weekend graphs is nearly two times more than a load of typical graphs. It is noted that there are no daily off-peak loads in plotted weekend graphs as it was in typical graphs.
The graph configuration of the workdays remains permanent but has changed a lot for the weekend graphs. All the specific points of the workdays graph remained the same as in the typical graphs. But the morning maximum has disappeared from the weekend graphs.
Updated load graphs quite differ from the typical graphs. Earlier, there were fewer household devices and wealth status of the population was lower. There were fewer computers and other microprocessing devices in households. These data are typical for large cities. But it can be markedly different from the loads in small towns.
For public buildings, the electric loads were calculated at the inputs of three different buildings by the demand factor method (SoR 256) and by the method of specific loads (GD 34). The differences between electric loads reach tremendous values.
It was expected that the values calculated by aggregate specific loads (by GD 34), would overestimate the values calculated by SoR 256. However, you can see this dynamic only for a grocery store. The load for the music school and the design organization contrariwise turned out to be lower than the values calculated by SoR 256.
To summarize, the results of electric load for the residential and public buildings indicate the need to clarify the reference literature and the update of the typical daily load graphs.

7. References
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