

# Dynamics of electric and magnetic fields in case of the urban environment

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**Abstract.** This paper studies the temporal dynamics of power-line frequency electric and magnetic fields in Saint-Petersburg and environs. It is found that electromagnetic fields generated by high-voltage transmission lines (HVTL) constantly change, depending on their loading and weather conditions. The dependence on weather conditions involves both the direct effect of air electrical conductivity as a function of its humidity, and indirect effects including the dependence of energy consumption on temperature and also the correlations between meteorological characteristics. An attempt has been made to evaluate the role of influencing factors.

## 1 Introduction

Electromagnetic pollution as a complex and dynamic process is characterized not only by spatial variability [1], but also by temporal dynamics. If mapping based on one-time measurements at as many points as possible suffices to examine spatial variability employing a common methodology within a limited period, then temporal dynamics can be studied only within monitoring, namely, multiple systematic measurements, also using the common methodology at the same points. Electromagnetic pollution is subject to fast changes depending on work of electrical networks and the equipment, and also extend in the changeable air environment. Practical measures for protection of the population must have to consider a real electromagnetic situation.

## 2 Materials and Methods

From 2017, we monitor the electromagnetic fields of industrial frequency in St. Petersburg. With very few examples of monitoring the electromagnetic fields, to date, it is nearly the longest and most extensive experience of this type. An example of the last similar research dates back to early 1990s in St. Petersburg [2], when considerable seasonal and daily fluctuations of indicators, with maxima in the daytime and, especially, in the evening “rush” hours with winter values generally higher than the summer ones, were identified. Meanwhile, in some foreign publications [3, 4, 5], assessments are made of and conclusions are drawn about the compliance of HVTL electric and magnetic fields at different distances

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from them with the hygienic standards and on possible health effects based on one-time measurements or calculations, i.e., the indicators of HVTL electromagnetic fields are a priori accepted as constant.

In our research, the electric and magnetic fields were monitored using the Gigahertz Solutions ME 3830 B M/E Analyser, involving measurements of electric field strength and magnetic induction, made at a height of 1.8 m:

- measurements of HVTL electric field strength and magnetic induction on 4 sites within 3.5 years, where, as of February 2021 about 160 series of measurements were made directly under wires in places of their maximum sagging, and 5, 10, 15, etc. m from them, and on 4 sites under similar conditions during 1 year (54 series of measurements);
- measurements of the width (in meters, counting from the last HVTL wire projection) of zones, where the electric field strength values are higher than 1000 and 2000 V/m and magnetic induction values are higher than 1000 and 2000 nT;
- measurements of magnetic induction from a complex of sources in residential zones, at 3 points, at each of which about 70 measurements had been made throughout 2017 (an annual cycle).

The results were mathematically processed employing cluster and correlation analysis methods. To analyse and demonstrate interrelations between concentrations of elements, the Ward's method was chosen as the most suitable [6]. On the first step, it is supposed that each cluster contains one object. First, two nearest elements are combined to form a class, then the objects are grouped that minimize the sum of squared distance for any two clusters, which can be created on each step.

## 3 Results and Discussion

### 3.1 General characteristic

From the results of our research, it can be stated, first of all, that HVTL electric and magnetic fields vary considerably. At the same time, for all 4 sites, where measurements were carried out within 3.5 years, similar tendencies are evident:

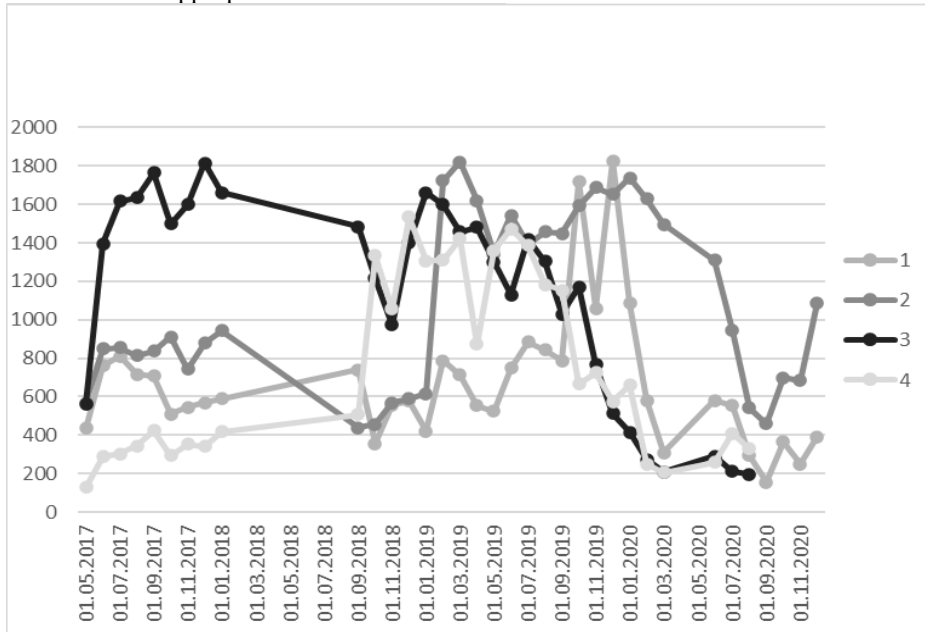
- growth of strength from spring 2017 to autumn 2018;
- relatively high, but unstable values from autumn 2018 to autumn 2019 - spring 2020;
- a decrease in late 2019 - early 2020.

Similar tendencies are noted also concerning magnetic induction and width of zones with high strength values (more than 1000 V/m and 2000 V/m). To construct a graph (fig. 1) and compile the tables below, the closest to wires points of sites were selected, where no overruns in device measurements were registered (up to 2000 V/m and 2000 nT).

It is important to note that for the most loaded HVTL from those studied, namely, HVTL-330 kV in the area of the Devyatkino subway station (and, in general, for the system of 5 parallel HVTL passing there), the width of a threshold band of the maximum permissible for residential zones strength of 1000 V/m (according to the SanPiN 2.1.2.2645-10) during observations reached 79 m, what exceeds the standard width of the sanitary protection zone almost fourfold (20 m for HVTL-330 kV according to the SanPiN 2.2.1/2.1.1.1200-03). It creates an environmental problem for the Murino town, where this HVTL system is located now due to the development of mass multistorey housing construction.

The specified periods of the growth of high (including unstably high) values and also of recession (and new growth on sites 1 and 2) correspond to neither calendar periods, nor seasons, and hardly can reflect anything, except for changing HVTL load. As regards a load fall in 2020, it is logical to assume that it occurred due to a decreased demand in electric

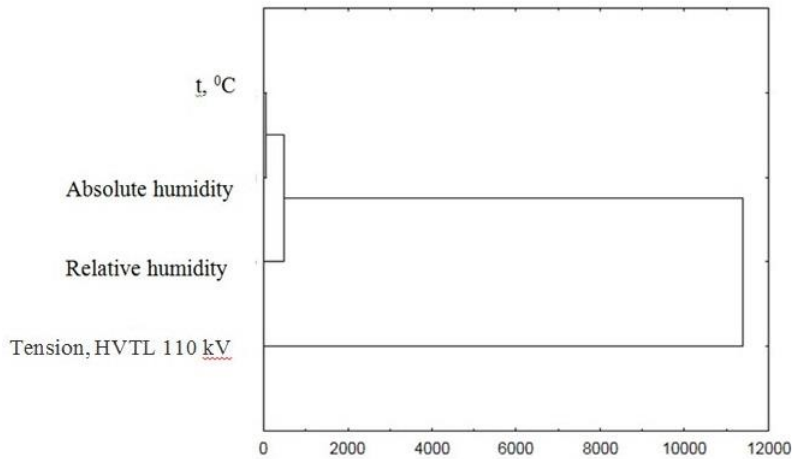
energy in conditions of economic decline owing to the spread of a novel coronavirus infection and the appropriate restrictive measures.



**Fig. 1.** Graph of the behaviour of average monthly values of electric field strength (V/m) at the points of sites: 1) HVTL 220 kV at the Devyatkiно subway station, 25 m from the end wire; 2) HVTL 330 kV at the intersection of Aviatorov Baltiki Avenue and Petrovsky Boulevard St., 50 m from the end wire; 3) HVTL 110 kV near the intersection of the avenues of Marshal Blyukher and Kondratyevsky, 20 m from the end wire; 4) HVTL 330 kV at the intersection of the avenues of Marshal Blyukher and Kondratyevsky, 25 m from the end wire.

To identify the dependence on influencing factors, the coefficients of correlation were defined and dendrograms of relationships between electric field strength and climatic indicators were constructed: temperatures, absolute humidity, relative humidity. Dendrograms were constructed by the Ward's method, the Euclid's distance. Correlations with atmospheric pressure were insignificant in all cases. On the presented dendrogram (Fig. 2), a weak dependence can be seen of the increased electric field strength on climatic indicators, what is confirmed by correlation coefficients and is further detailed.

Changes in HVTL loading is the most important, but not the only reason for dynamics of the indicators of electromagnetic and, in particular, electric fields. Fields are distributed over aerial environment, and its dielectric properties cannot but depend on the current properties, specifically, on humidity, directly affecting electric conductivity, and temperature and atmospheric pressure, indirectly related to humidity. To determine a role of the factors influencing the dynamics of electromagnetic HVTL fields, the correlation relationships were computed between the characteristics of electromagnetic fields (strength, magnetic induction, width of the zones of high strength values) and meteorological characteristics at the time of measurement, at different sampling options. Meteorological characteristics were accepted according to the [https://rp5.ru/Pogoda\\_v\\_sankt-St. Petersburg](https://rp5.ru/Pogoda_v_sankt-St.-Petersburg) Internet service data.



**Fig. 2.** Dendrogram of interrelation between the increased strength of the HVTL-110 kV electric field under wires and weather indicators: temperature, absolute humidity, relative humidity near the intersection of Marshal Blyukher and Kondratyevsky avenues, by the Ward's method (the Euclid's distance).

### 3.2 Correlation indicators over the total period of monitoring

Correlation indicators over the total period of monitoring are presented in table 1.

**Table 1.** Coefficients of correlation between the characteristics of electromagnetic fields and indicators of meteorological conditions for complete samples over 2017-2021.

| Monitored locations  | Coefficients of correlation considering measures: |                   |                   |
|--|---|-------------------|-------------------|
|  | Air temperature                                   | Relative humidity | Absolute humidity |
| HVTL 220 kV at the Devyatkinno subway station, n=156                                   |   |                   |                   |
| Tension, 25 m from last wire   | 0.004   | -0.106            | <b>0.366</b>      |
| Magnetic induction, 25 m from last wire  | <b>-0.453</b>                                     | <b>0.284</b>      | <b>-0.360</b>     |
| Width of zone above 1000 v/m   | -0.139  | 0.063             | -0.184            |
| HVTL 330 kV on crossing of Aviatorov Baltiki Avenue and Petrovsky Boulevard St., n=160 |   |                   |                   |
| Tension, 50 m from last wire   | -0.028  | -0.100            | -0.126            |
| Magnetic induction, 30 m from last wire  | -0.013  | -0.075            | -0.087            |
| Width of zone above 1000 v/m   | 0.008   | -0.112            | -0.077            |
| HVTL 110 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues, n=147       |   |                   |                   |
| Tension, 15 m from last wire   | -0.100  | 0.041             | -0.093            |
| Magnetic induction, under the last wire  | <b>-0.276</b>                                     | -0.075            | <b>-0.340</b>     |

| Monitored locations  | Coefficients of correlation considering measures: |                   |                   |
|--|---|-------------------|-------------------|
|  | Air temperature                                   | Relative humidity | Absolute humidity |
| Width of zone above 1000 v/m   | -0.100  | 0.038             | -0.079            |
| HVTL 330 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues, n=147 |   |                   |                   |
| Tension, 30 m from last wire   | -0.156  | -0.092            | -0.211            |
| Magnetic induction, 10 m from last wire  | -0.222  | -0.039            | -0.184            |
| Width of zone above 1000 v/m   | -0.127  | -0.090            | -0.198            |

Note: hereinafter significant relationships are highlighted in bold.

As table 1 indicates, in case of complete samples collected over 2017-2021, correlations with meteorological characteristics are generally loose. However, when the scope of sampling is considerable, some of correlation coefficients reach a significance importance threshold ( $r/Sr \geq 3$ ). To analyse the results and identify the relationship of genetic nature, it should be noted that the electromagnetic field of power objects has a pronounced stationary or quasi-stationary pattern that allows the electric and magnetic fields to be considered as the functions, which are independent of one another, and also that the electric HVTL field does not virtually depend on loading and is completely defined by strength, whereas the magnetic field, on the contrary, depends greatly on loading [6]. Significant coefficients of correlation between characteristics of electromagnetic fields and indicators of meteorological conditions can reflect:

- direct dependence of the characteristics of electromagnetic fields on dielectric air properties caused by meteorological conditions, what is possible for electric fields and is improbable for magnetic fields that have a high penetrating capacity [7];
- indirect dependence of the characteristics of electromagnetic fields on energy consumption variable due to meteorological conditions and, respectively, HVTL loading, what can properly explain the revealed inverse dependencies of magnetic induction on temperature and absolute humidity, which substantially increases in summer;
- simultaneous change of mutually independent indicators affected by an unknown external factor.

### 3.3 Correlation indicators for cold, warm and transition periods

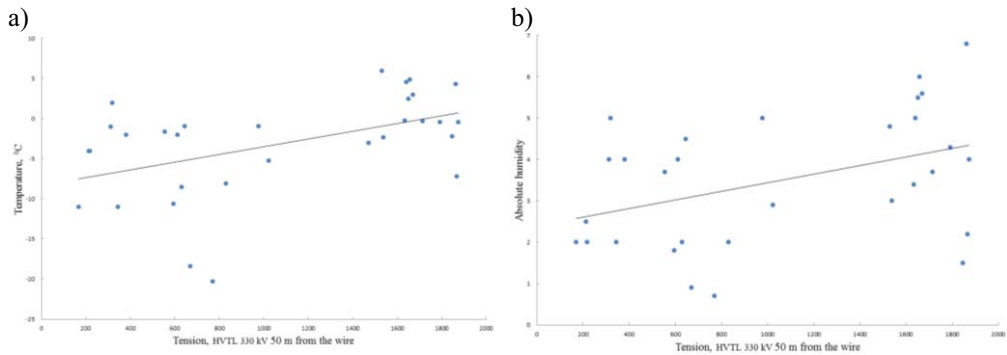
Correlation relationships for cold, warm and transition periods are presented in tables 2 and 3. Samples integrate the results of measurements over various years, hence, quite probable differences in HVTL loads are not considered. Nevertheless, as evident from table 2, correlation coefficients are higher, than for complete samples (table 1), and statistically significant correlations are noted more often, despite smaller sample volumes. Typical also is that significant relationships are identified for the HVTLs passing by the Devyatkinno subway station and used to export electric energy to Finland as opposed to the HVTL near the intersection of Marshal Blyukher and Kondratyevsky avenues providing intra-urban power supply [11]. Loading and voltage of intra-urban HVTLs are less steady. No significant relationships with atmospheric pressure were found.

**Table 2.** Coefficients of correlation between strength of electric fields and indicators of meteorological conditions for the samples collected over cold, warm and transition periods

| Monitored locations   | Coefficients of correlation considering measures: |                   |                   |
|---|---|-------------------|-------------------|
|   | Air temperature                                   | Relative humidity | Absolute humidity |
| HVTL 220 kV at the Devyatkinno subway station                                   |   |                   |                   |
| Tension, 25 m from last wire  | <b>0,334</b>                                      | 0,017             | 0,260             |
|   | 0,220   | -0,112            | -0,049            |
|   | -0,162  | <b>-0,371</b>     | 0,046             |
| Width of zone above 1000 v/m  | 0,172   | -0,099            | 0,106             |
|   | 0,103   | -0,163            | -0,206            |
|   | -0,218  | 0,113             | -0,189            |
| HVTL 330 kV on crossing of Aviatorov Baltiki Avenue and Petrovsky Boulevard St. |   |                   |                   |
| Tension, 50 m from last wire  | <b>0,475</b>                                      | -0,267            | <b>0,409</b>      |
|   | 0,207   | <b>-0,393</b>     | -0,221            |
|   | 0,109   | -0,104            | 0,011             |
| Tension, 70 m from last wire  | <b>0,384</b>                                      | <b>-0,397</b>     | 0,263             |
|   | 0,141   | -0,267            | -0,162            |
|   | 0,152   | -0,234            | -0,044            |
| Width of zone above 1000 v/m  | <b>0,390</b>                                      | -0,331            | 0,236             |
|   | 0,268   | -0,291            | -0,045            |
|   | 0,107   | -0,097            | -0,034            |
| HVTL 110 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues       |   |                   |                   |
| Tension, 15 m from last wire  | 0,037   | -0,058            | 0,058             |
|   | 0,185   | -0,230            | -0,130            |
|   | 0,064   | 0,099             | 0,172             |
| Width of zone above 1000 v/m  | 0,076   | 0,097             | 0,056             |
|   | 0,153   | -0,210            | -0,116            |
|   | -0,030  | 0,110             | 0,106             |
| HVTL 330 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues       |   |                   |                   |
| Tension, 30 m from last wire  | 0,250   | -0,310            | 0,055             |
|   | 0,176   | -0,145            | -0,249            |
|   | -0,023  | 0,084             | -0,012            |
| Width of zone above 1000 v/m  | 0,137   | -0,290            | -0,038            |
|   | 0,219   | -0,141            | -0,252            |
|   | 0,037   | -0,025            | 0,075             |

Note: the first figures in the table cells characterize cold periods (January-February), the second ones - warm periods (June-August), the third ones - transitional periods (March-May, September-December).

The dependence of strength on such meteorological characteristics as temperature and humidity, increases during cold periods (Fig. 3). Of note also are invariable signs of relationships, including those statistically significant. Significant relationships with temperature are only direct, and they are found only in cold periods. There is no information about the effect of temperature conditions on dielectric air properties only during cold periods. Therefore, the most probable explanation for this regularity is HVTL undervoltage owing to an increased energy consumption at low temperatures.



**Fig. 3.** Graphs of dependence of the strength of HVTL-330 kV electric fields at the Devyatkinno subway station and indicators of meteorological conditions during cold periods. a) on temperature; b) on absolute humidity.

Relationships with relative humidity, as evident from tab. 2 are only inverse, detected during all seasons. An increased humidity weakens dielectric air properties, and it involves a decrease in strength. A direct relationship with absolute humidity is indirect. It reflects similar relationship with temperature as these characteristics are rather closely interrelated.

Thus, the influence of weather conditions on the strength of HVTL electric fields can be manifested both directly, through air conductivity, which depends on humidity, and indirectly, through the dynamics of energy consumption, which depends on weather conditions. No significant relationships with atmospheric pressure were likewise revealed.

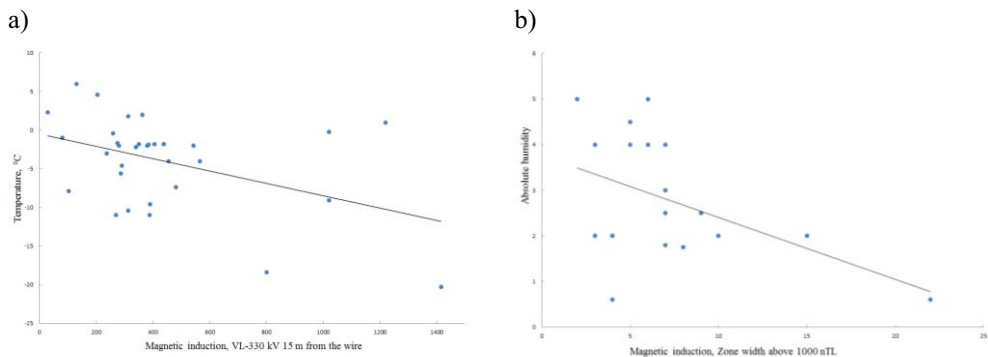
**Table 3.** Coefficients of correlation between the characteristics of magnetic induction and indicators of meteorological conditions for samples collected over cold, warm and transition periods

| Monitored locations   | Coefficients of correlation considering measures: |                   |                   |
|---|---|-------------------|-------------------|
|   | Air temperature                                   | Relative humidity | Absolute humidity |
| HVTL 220 kV at the Devyatkinno subway station                                   |   |                   |                   |
| Magnetic induction, 10 m from last wire   | -0,159  | 0,194             | -0,029            |
|   | 0,256   | -0,373            | -0,122            |
|   | -0,100  | 0,060             | -0,097            |
| Width of zone above 1000 nT   | -0,135  | 0,336             | 0,046             |
|   | -0,085  | 0,164             | 0,141             |
|   | -0,154  | -0,086            | -0,215            |
| HVTL 330 kV on crossing of Aviatorov Baltiki Avenue and Petrovsky Boulevard St. |   |                   |                   |
| Magnetic induction, 10 m from last wire   | 0,025   | -0,097            | -0,015            |
|   | -0,026  | -0,015            | -0,169            |
|   | 0,165   | -0,344            | -0,058            |
| Magnetic induction, 30 m from last wire   | 0,134   | -0,155            | 0,115             |
|   | 0,021   | -0,030            | -0,215            |
|   | 0,311   | -0,192            | 0,166             |
| Width of zone above 1000 nT   | -0,069  | -0,023            | -0,012            |
|   | 0,096   | -0,002            | 0,320             |
|   | 0,018   | -0,226            | -0,202            |
| HVTL 110 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues       |   |                   |                   |

|   |               |        |               |
|---|---------------|--------|---------------|
| Magnetic induction, 10 m from last wire                                   | -0,245        | 0,142  | -0,176        |
|   | -0,105        | 0,174  | 0,051         |
|   | -0,050        | 0,180  | 0,070         |
| HVTL 330 kV at crossing of the Marshal Blyukher and Kondratyevsky avenues |               |        |               |
| Magnetic induction, 15 m from last wire                                   | <b>-0,436</b> | 0,106  | -0,304        |
|   | 0,228         | -0,172 | -0,111        |
|   | 0,071         | 0,024  | 0,156         |
| Magnetic induction, 30 m from last wire                                   | <b>-0,420</b> | -0,078 | -0,274        |
|   | -0,171        | -0,098 | -0,088        |
|   | 0,072         | -0,171 | -0,035        |
| Width of zone above 1000 nT   | <b>-0,564</b> | -0,236 | <b>-0,535</b> |
|   | -0,210        | 0,206  | 0,168         |
|   | -0,219        | 0,045  | -0,197        |

Note: the first figures in the table cells characterize cold periods (January-February), the second ones - warm periods (June-August), the third ones - transitional periods (March-May, September-December).

As evident from table 3 and fig. 4, for the magnetic induction reflecting HVTL loading [6], significant inverse relationships with meteorological conditions emerge during cold periods on intra-urban lines and are almost non-existent on export lines. In view of high permeability of magnetic fields, this is not about direct, genetic dependence. However, the revealed specifics is quite well explained by an increase in the HVTL load at low temperatures, accompanied by low absolute humidity.



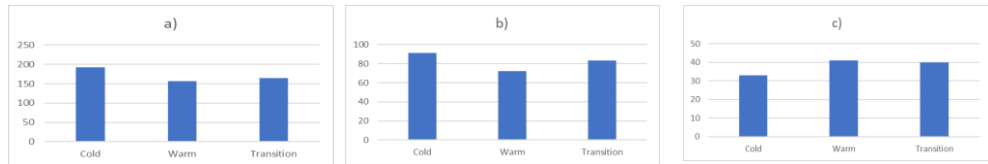
**Fig. 4.** Graphs of dependence of the strength of HVTL-330 kV magnetic induction near the intersection of Marshal Blyukher and Kondratyevsky avenues and indicators of meteorological conditions during cold and transition periods. a) on temperature (cold periods); b) on absolute humidity (transition periods).

### 3.4 Specifics of seasonal dynamics and correlation relationships in residential zones

The strengths of electric fields located more than 100-150 m away from HVTL nowhere reach the significant values higher than 1-5 V/m. At the same time, the magnetic fields of industrial frequency with the magnetic induction values of about tens and hundreds nT are fixed everywhere, except for forest parks. Measurements in a residential zone showed that magnetic fields have seasonal dynamics and depend on the social factors, influencing energy consumption. At the points located in residential areas, near multistorey apartment houses, maxima are due to cold periods, and minima – to warm periods (Fig. 5 a, b). Near the metro station (Fig. 5 c), the dynamics is less readily seen.



An increase in electrical grid load in wintertime and a subsequent growth in magnetic induction are a matter of common knowledge. In cases when the electric power plays a significant role in heating dwellings, the winter growth in magnetic induction is much faster. So, in the historic centre of Trondheim (Norway), the average values of magnetic induction are 130 nT in summer (that is rather close to our data for St. Petersburg and other cities of Russia) and 850-900 nT in winter [8]. Such a difference is quite natural since, according to a specialized website [9], in Norway up to 70 percent of inhabitants use electricity as the main source of heat. Its dependence on meteorological conditions (tab. 4) almost entirely disappears in the residential St. Petersburg zone during cold periods, along with a relatively low growth of magnetic induction. This is the opposite to the above-described annual dynamics of HV line electromagnetic fields.



**Fig. 5.** Average seasonal values of magnetic induction (nT) at the points of monitoring: a) St. Petersburg, Ushinsky St., 15, building 1; b) St. Petersburg, Grazhdansky Avenue, 114, building 6; c) St. Petersburg, the subway station Grazhdansky Avenue.

**Table 4.** Coefficients of correlation between magnetic induction values in a residential zone and indicators of meteorological conditions

| Monitored locations                                   | Coefficients of correlation considering measures: |                   |                   |
|---|---|-------------------|-------------------|
|   | Air temperature                                   | Relative humidity | Absolute humidity |
| St. Petersburg, Ushinsky St., 15, building 1          |   |                   |                   |
| Cold period   | -0,049  | 0,053             | -0,066            |
| Warm period   | -0,216  | -0,033            | -0,220            |
| Transition periods                                    | -0,337  | 0,025             | 0,034             |
| St. Petersburg, Grazhdansky Avenue, 114, building 6   |   |                   |                   |
| Cold period   | -0,092  | -0,101            | 0,163             |
| Warm period   | <b>-0,540</b>                                     | 0,225             | -0,211            |
| Transition periods                                    | -0,183  | 0,173             | <b>-0,468</b>     |
| St. Petersburg, the subway station Grazhdansky Avenue |   |                   |                   |
| Cold period   | -0,060  | 0,046             | -0,003            |
| Warm period   | <b>-0,432</b>                                     | 0,287             | -0,195            |
| Transition periods                                    | 0,286   | -0,146            | -0,229            |

An inverse dependence of magnetic induction on humidity and temperature reflects an out-migration of some population in summertime to vacation spots and reduction in using electrical household appliances and lighting. Of note is that this phenomenon arises directly in residential areas in warm and partly during transition periods.

## 4 Conclusions

High-voltage transmission lines are almost the only significant source of industrial frequency electric fields in urban conditions. The industrial frequency magnetic fields from both HVTL, and various other sources have higher penetration and manifest themselves everywhere. Both electric, and magnetic fields are characterized by complex spatial variability and temporal dynamics. A major factor influencing the electric and magnetic HVTL fields is their loading, a secondary factor - weather conditions affecting both dielectric air properties, and energy consumption and, respectively, HVTL loading. During cold periods, HVTL undervoltage owing to an increased energy consumption at low temperatures forms a weak direct dependence of strength on temperature and absolute humidity. At the same time, an increase in HVTL load at low temperatures, accompanied by low absolute humidity, creates weak inverse dependencies of magnetic induction on temperature and absolute humidity. In a residential zone, where magnetic fields are formed by numerous household sources and their power supply systems, the dependence on meteorological conditions appears, on the contrary, in warm and partly transition periods. Weak inverse dependencies of magnetic induction on humidity and temperature, taking place at this time, reflect an out-migration of some population in summertime and reduction in using electrical household appliances and lighting.

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