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Intelligent building systems as a tool for monitoring power consumption and quality in a building

Dr eng. Andrzej Ożadowicz
AGH-UST Krakow, Poland

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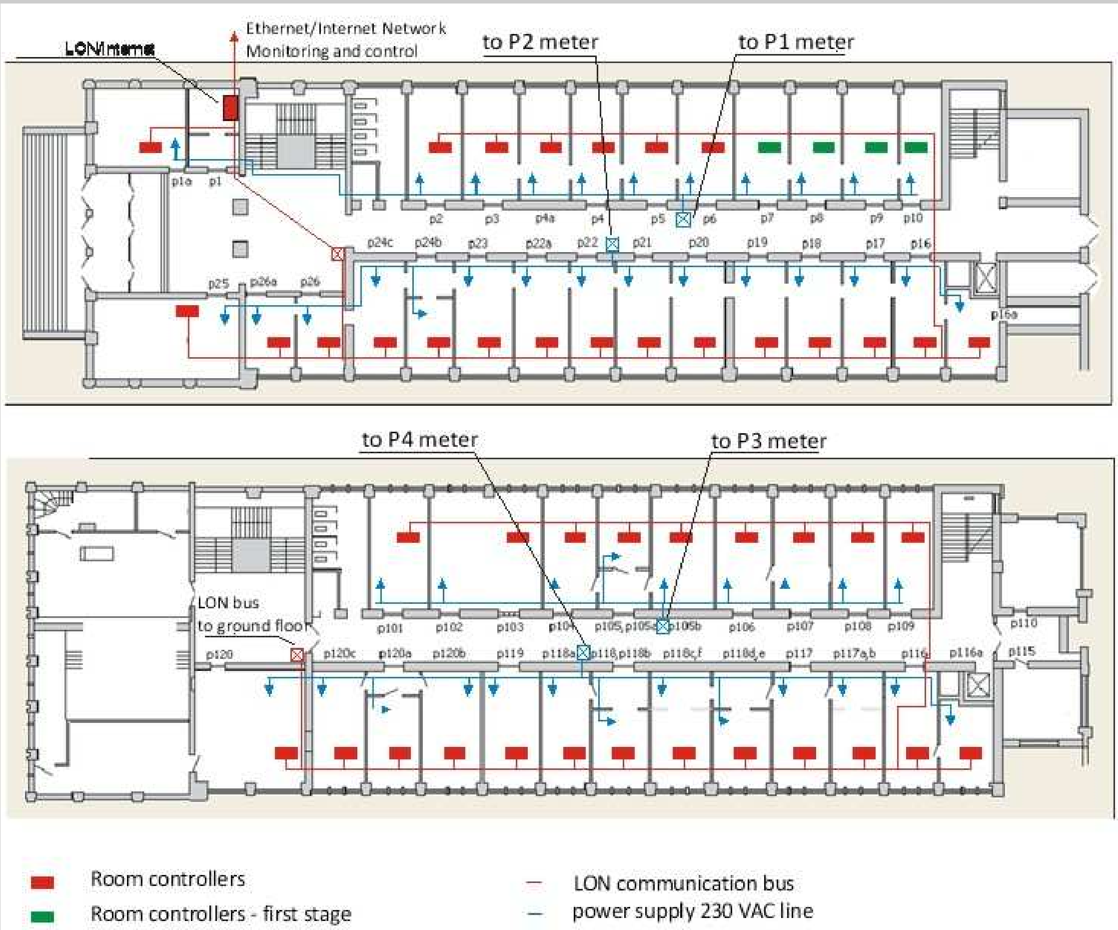


EPQU Magazine

An intensive development of distributed control systems in the industrial automation and intelligent building installations has been observed over recent years. The latter are extensively employed in public utility and office buildings, allowing for automatic control of building equipment, advanced lighting and temperature control as well as monitoring of selected parameters, essential for the building performance and comfort. Continuous development in electronics, IT and telecommunications, compels manufacturers of IB systems equipment to offer new and functionally more advanced components, while the systems employ state-of-the-art techniques of information transfer. Recently this equipment also includes electricity meters and power supply analyzers provided with interfaces to commonly used standards of building automation networks. These meters and analyzers enable full integration of building control and monitoring systems, using the same network for information exchange and data transmission. Two standards of such network are commonly used in Europe: KNX (European – formerly EIB) and LonWorks (American).

The aim of this paper is to acquaint the reader with the concept of the use of distributed control systems, and building automation systems based on them, as a tool for electric power consumption and power supply parameters monitoring.

Building automation systems

Building automation systems are de facto distributed control systems utilizing a communication bus, which connects all the system devices and enables data exchange among them. Usually the transmission medium is twisted pair or the already existing power network; a fiber-optic, radio link or other means, are less often used. The considered systems, both KNX and LonWorks, employ twisted pair as transmission medium. This solution determines maximum possible data transfer rates: 78 kbps for LonWorks and 9.6 kbps for KNX. For both systems a tree topology without possibility of loops was selected. Such configuration enables easy network extension with new devices and improves system reliability.

Each network device has its own software application, installed during the system configuration, which defines tasks to be executed in response to external signals from the bus and/or from the device input/output module. This basic information elements transferred via the system buses are EIS objects in the KNX standard, and the so-called standard network variables (SNVT) in LonWorks. Depending on the type of information carried, these objects (variables) differ in their bit length. For a simple information, e.g. on/off, they obviously are one-bit words, whereas for information on a temperature, current, power, etc. — 4, 8, 16 bit words. Appropriate variables are grouped in the so-called functional blocks, perceived by the user as the device software interface elements which, using configuration programs, are connected into function groups by the user. The functional connections of network devices, formed this way, constitute control and monitoring network. Such network is created using dedicated software packages, that can be run in the Windows environment and, through their graphical interface, support connecting the functional blocks and enable communication monitoring in the already functioning control network.

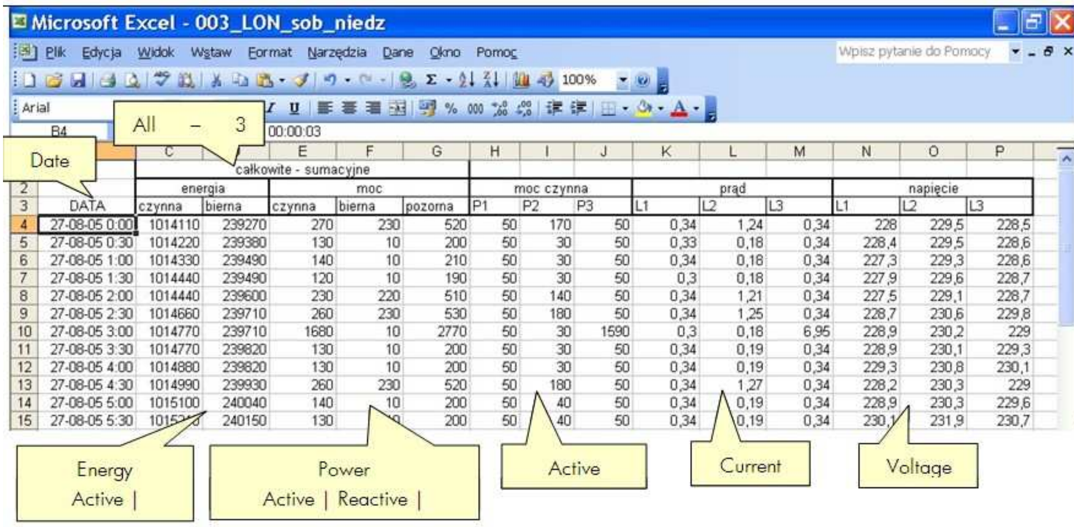
Building automation equipment in the power supply parameters monitoring

As already mentioned, electricity meters and power supply analyzers provided with network interfaces to intelligent building systems, become available on the market. Two such analyzers with interfaces supporting two most common in Europe standards of building automation system have been used in the authors study.

For the KNX standard it was a meter, which allows for watt-hour and VAr-hour measurements in 2-, 3- and 4-wire supply networks with balanced or unbalanced load. The power consumption data are computed from the supply network phase currents and voltages measurements. The current inputs of the meter are directly connected to the supply network, i.e. it requires no instrument transformers thus both the computations and readout do not involve any information on the transformation ratio. A wide range of the meter input currents: 0.05 A up to 65 A, should be emphasized. An embedded LCD display enables readout of measured values: active and reactive power, rms current and voltages in each phase, phase power factor in each phase, total power factor for wye-connection and power frequency. Reading data from the analyzer via the KNX system bus, the user can access the objects carrying the information on the active and reactive energy consumption as well as the instantaneous active and reactive power values (updated every 5 seconds). The meter transmits the instantaneous power values in the form of a telegram, either upon a parametrically defined change in the power value or, on the standard basis, every 8 seconds. The device is designed for installation on a standard mounting rail, and contains no mechanical parts in its measuring system; this makes the installation easier and improves its reliability. Communication with the system bus is carried out via the separate KNX-standard connector.

In the LonWorks system an advanced analyzer has been applied, what allows for detailed analysis of power supply parameters in a 3x230/400V AC three-phase network, in both four-wire and three-wire configuration. The analyzer measures instantaneous current and voltage values in the three-phase system. The sampling rate depends on the system frequency (50Hz or 60Hz) and each measured signal value is updated 32 times during the fundamental period of the system voltage. This sampling rate allows for measuring amplitudes of harmonic components of the order up to 15. Basing on the measured signals and real time computation, the analyzer provides the user with a comprehensive set of supply network parameters: rms current and voltage values, active, reactive and apparent power in each phase, power factor, active and reactive energy, amplitudes of harmonic components and total harmonic distortion factor THD. The analyzer module is provided with its own memory, which enables recording of measured signals over a period from 1 minute up to 4 days. The sampling time of recorded signals is set within the range from 0.3 s to 30 min. Up to 12 measured quantities can be stored in the memory.

The gathered data were used for preparing graphs that depict, in the user-friendly form, the selected parameters values, their variability in time and, when required, allow tracking the trend of changes over long periods of time. Figure 1 shows examples of Excel sheets with measurement data.



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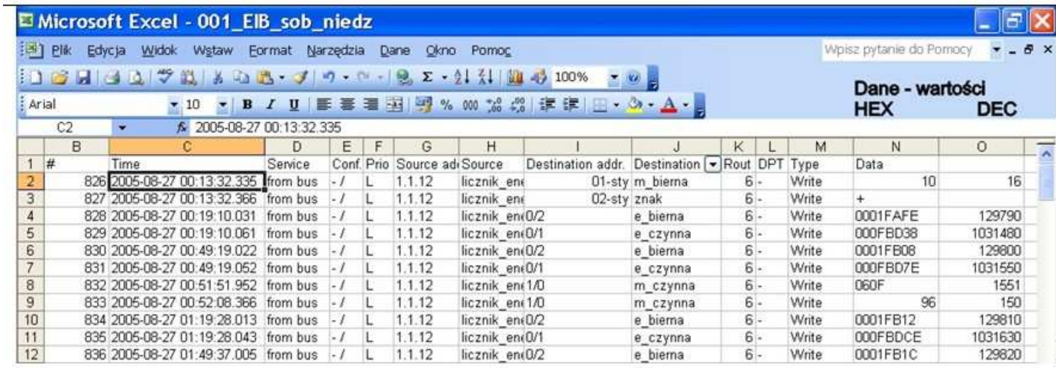

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4	828	2005-08-27 00:19:10.031	from bus	- /	L	1.1.12	licznik_ene	0/2	e_bierna	6	-	Write	0001FAFE	129790
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6	830	2005-08-27 00:49:19.022	from bus	- /	L	1.1.12	licznik_ene	0/2	e_bierna	6	-	Write	0001FB08	129800
7	831	2005-08-27 00:49:19.052	from bus	- /	L	1.1.12	licznik_ene	0/1	e_czynna	6	-	Write	000FBD7E	1031550
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11	835	2005-08-27 01:19:28.043	from bus	- /	L	1.1.12	licznik_ene	0/1	e_czynna	6	-	Write	000FBDCE	1031630
12	836	2005-08-27 01:49:37.005	from bus	- /	L	1.1.12	licznik_ene	0/2	e_bierna	6	-	Write	0001FB1C	129820

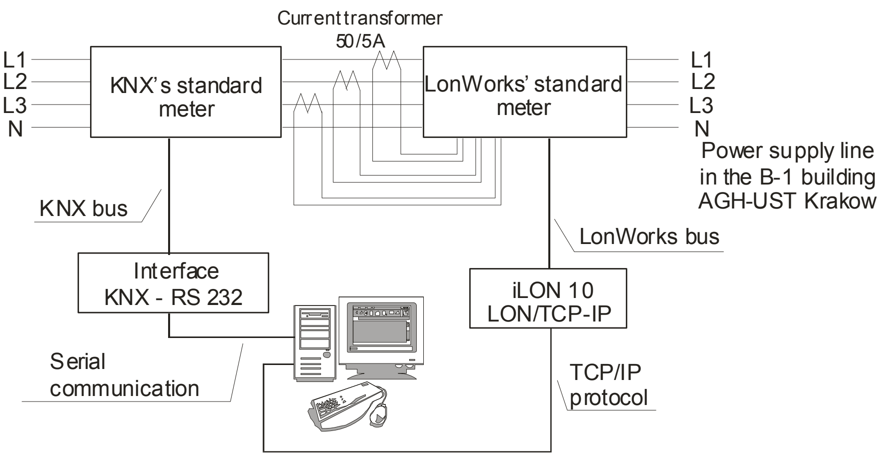
b)

Fig. 1 – Data acquisition windows: a) for the LonWorks standard, b) for the KNX standard

Basic measurements of energy consumption and power quality parameters

For the research purposes the meters were installed on a feeder supplying office rooms and lecture rooms in one of the AGH-UST buildings. A schematic diagram of the measuring system is shown in figure 2.

Fig. 2 – Schematic diagram of the measuring system



The measurements presented in this paper were carried out in 2005. They covered, including minor breaks, a period of three months — August, September and October. In each month four days in a week: Tuesday, Wednesday and Saturday, Sunday were selected. It should be mentioned that these months differ in terms of energy consumption. August is a holiday month, with the so-called economical maintenance regime at the University, so there are a small number of loads connected and the power consumption is low. October is the first month of academic year when the number of loads connected to the network increases significantly. September can be regarded as an intermediate period between these two months with very low and high power consumption (a small and large number of loads connected, respectively). Figure 3 shows the time characteristics of active energy consumption, obtained from the analyzer A2000 and the meter DZ 4000 KE.

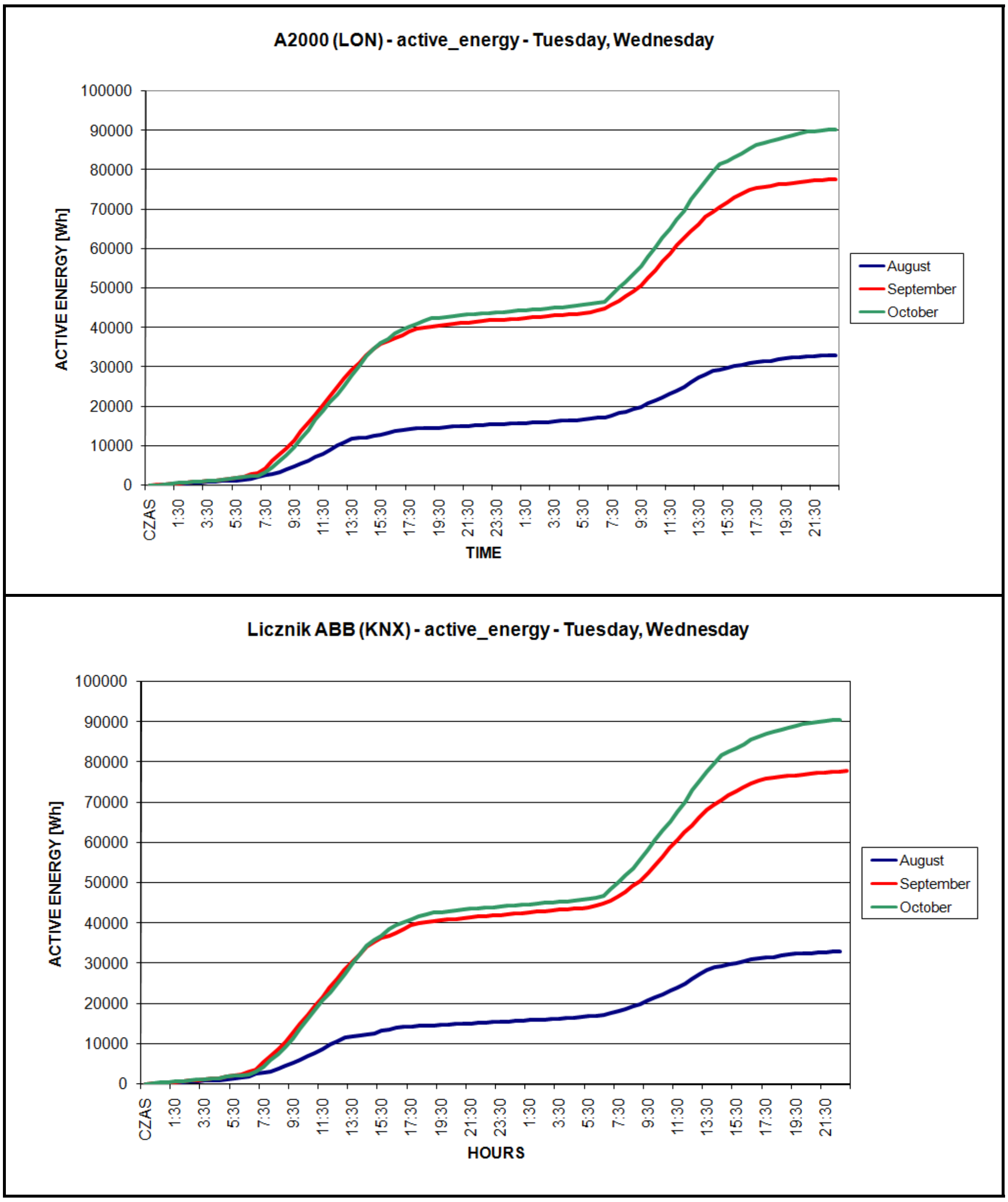


Fig. 3 Active power consumption

The KNX-standard meter can only transmit the data on consumed power and instantaneous load in any phase of the power supply system (the so-called instantaneous powers). More information on the actual conditions of the power supply network can be obtained from graphs plotted using the data from a more sophisticated analyzer, operating in the LonWorks system. As an example, the time characteristics of active, reactive and apparent power are shown in figure 4, and rms phase voltage changes in are shown in figure 5.

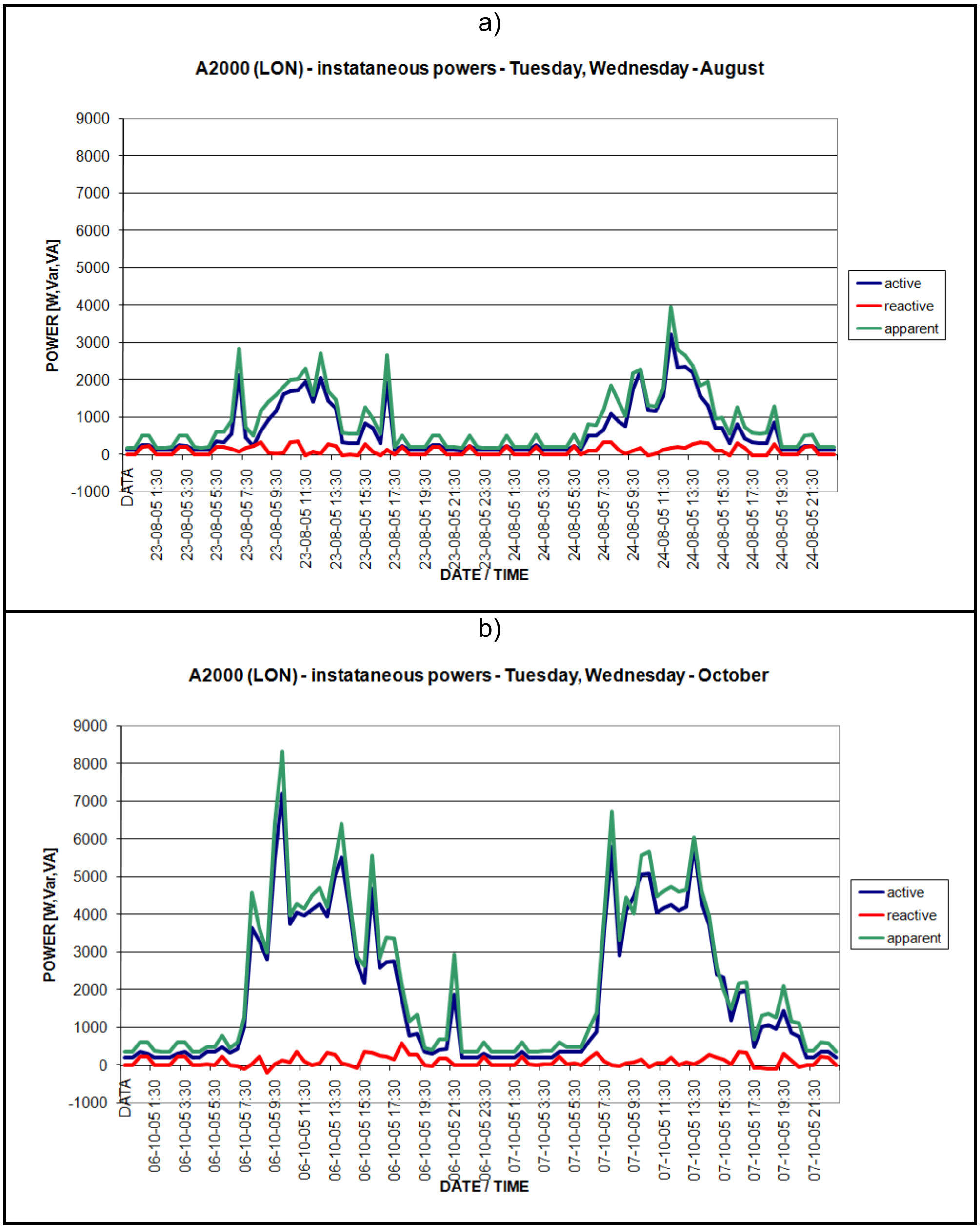


Fig. 4 – Time graphs of active, reactive and apparent power demand — Tuesday, Wednesday

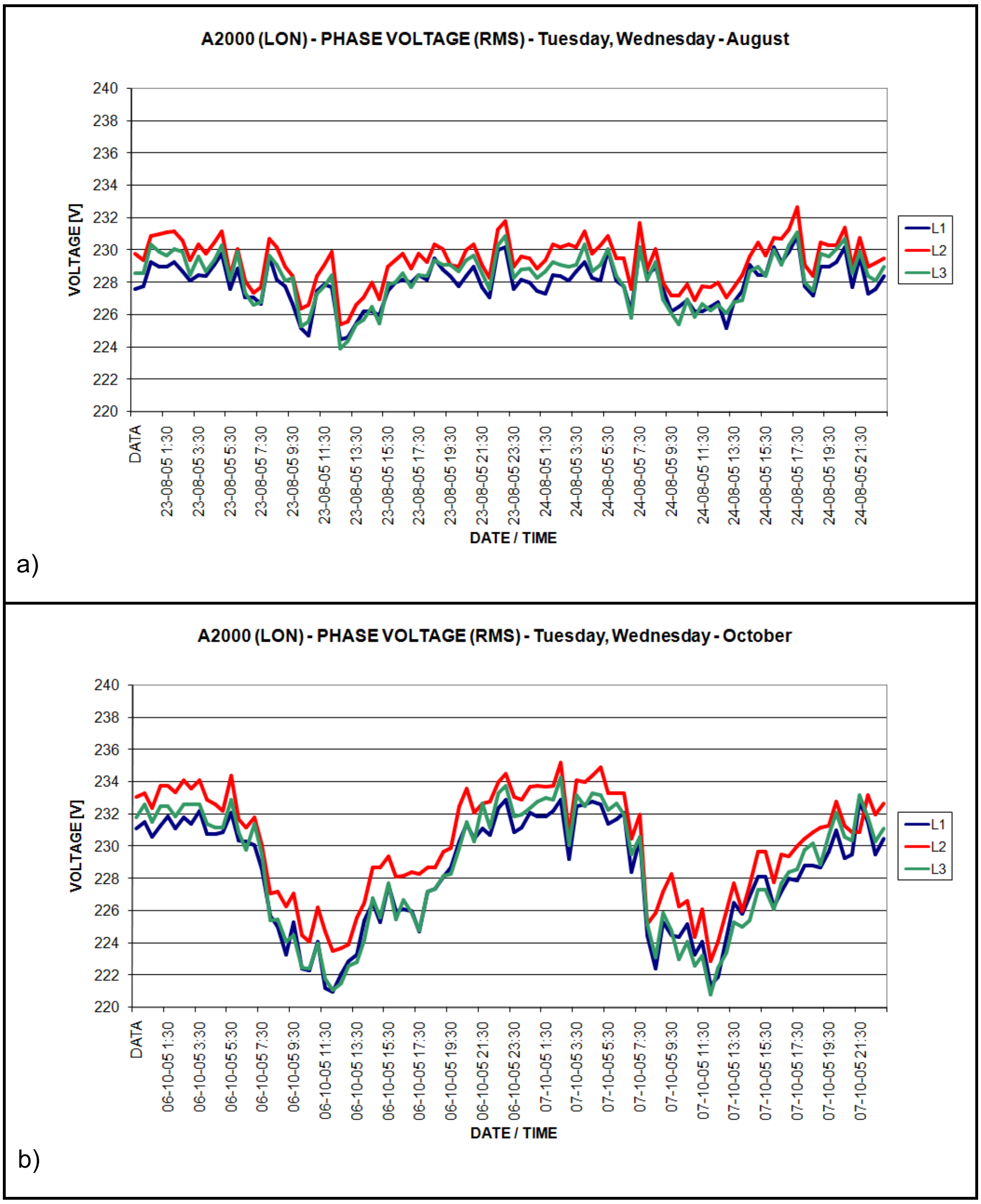
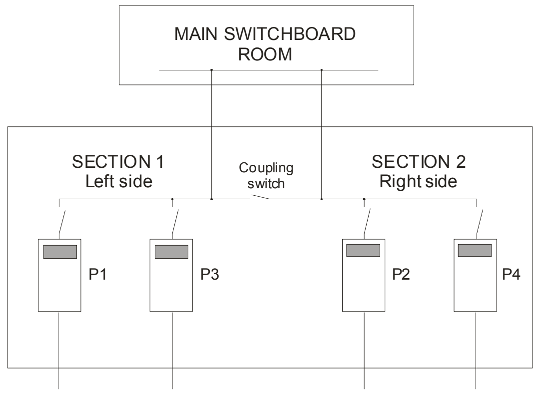


Fig. 5 – Time characteristics of rms phase voltage in 3 phases of the power supply network

Analysis of the graphs prepared using the data gathered by LonWorks and KNX systems, shows that they can be utilized in monitoring, control and assessment of basic parameters of a building power supply. The graphs clearly show how rms supply voltage changes range depends on the chosen period of time, i.e. on the number of loads connected to the supply network. Information on the rms voltage value changes can be a substantial ground for claims against the electric power supplier for failure to comply with agreed power supply quality. Since the monitoring provides information on the power demand, the line load as well as the power consumption can be assessed on the continuous basis. Telegrams carrying the information on the power consumption can also be used in settlements between customers and a distribution company, provided the meters are certified. Since data are available in the digital form they can be easily acquired and used for further applications, like analyses, reports or determining trends in behavior of selected quantities or parameters.

Long-term measurements of power consumption in electric power supply system

Another field of study were long-term measurements of power consumption in the existing electrical installation of the Faculty of Electrical Engineering, Automatics, Computer Science and Electronics building AGH-USC, Krakow. In this building a pilot system of building automation was installed in 1998 – 2002. Initially, the system included only 4 faculty staff rooms and later it was extended for all rooms (lecture rooms, office rooms, etc.) on the ground floor and the first floor. The system is based on the LonWorks standard. Office and lecture rooms were provided with room controllers, whose purpose is automatic control of lighting and switching light off when the room is not occupied, temperature sensor modules and temperature set point modules, as well as electrically actuated thermostatic radiator valves which control the room temperature according to day/night schedule stored in the set point module.
Concurrently with the erection of the pilot installation the power consumption measuring system was implemented. The measuring system employs electromechanical induction meters, already installed in the switchboard room, and modules that convert rotor disc revolutions into discrete pulses. Since these modules do not support data transmission over the LonWorks network the number of pulses, proportional to the power consumed, is read by a recorder in 15-minute intervals. The data are written into text files, separate for each meter, and stored in computer memory. The file contains information on the date and time of measurement and the number of pulses counted. After processing, the recorded data were used to prepare graphs shown in figures 8, 9 and 10 below. The building electrical installation, supplying the floors where the pilot system LonWorks is installed, has two sections, separate for the left and right side of the building, and each section has two branch circuits corresponding with the building floors. The configuration of the switchboard connections is shown in figure 6.



P1	Ground floor — left side (faculty rooms); here the pilot installation for 4 rooms was erected.
P2	Ground floor — right side (Dean's office and faculty staff rooms)
P3	First floor — left side (faculty rooms and lecture room)
P4	First floor — right side (faculty rooms)

Fig. 6 – The distribution switchboard and sections diagram

Structural diagrams of the electrical installation and building automation system for the ground floor and the first floor are shown in figure 7.

The measurement data sets were recorded for each day since 2000 till the end of 2004. In some days there are lacks of data, which randomly occurred for technical reasons, in spite of proper operation of the measuring modules. Finally, taking into account all these gaps in data, the percentage indices of data gathering efficiency were computed for each year over the recording period. These indices show the percentage of time in covered by correct measurements in a given year and utilized in the analysis: 2000 – 96.9%, 2001 – 99.8%, 2002 – 71.3%, 2003 – 99,9% and 2004 – 72.6%.

Because of long duration of the measurement periods a statistical interpretation of gathered data employing both average and maximum values in 15-minute intervals was applied. As a reference for comparing the electric power consumption levels were taken the average and maximum values in consecutive months in years 2000 – 2004, separately for each meter. The results, presented in the form of line graphs and histograms, allow for easy interpretation and analysis of power consumption trends over long periods of time.

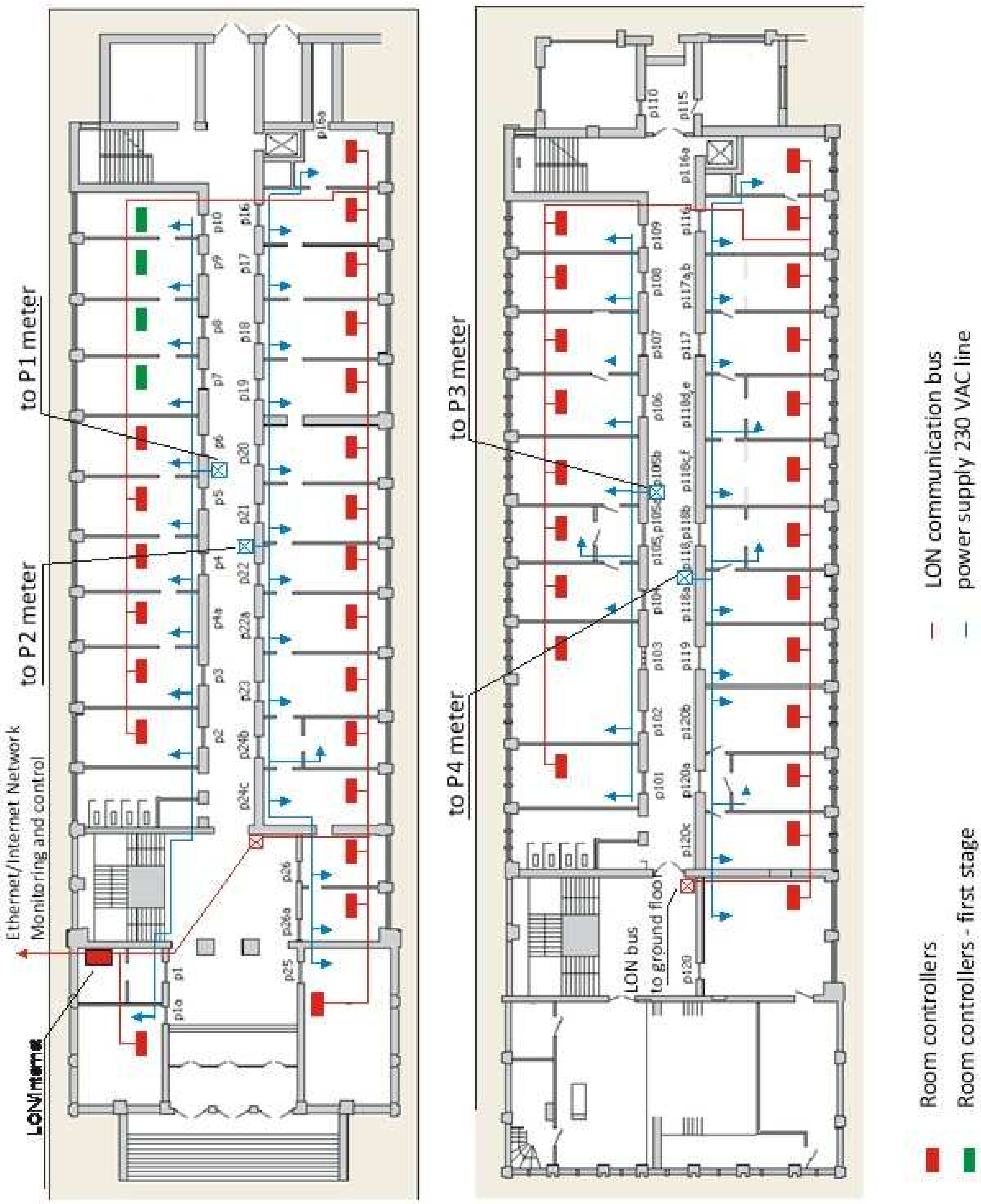


Fig. 7 – Diagram of electrical installation and LON network in the AGH-UST building

The purpose of graphs, presented further in this paper, is to show some options of measurement data interpretation as well as demonstrate how the power consumption in the public utility building has changed after installation of the building automation system.

The histograms in figure 8 show differences in the power consumption in consecutive years with respect to the level in 2000.

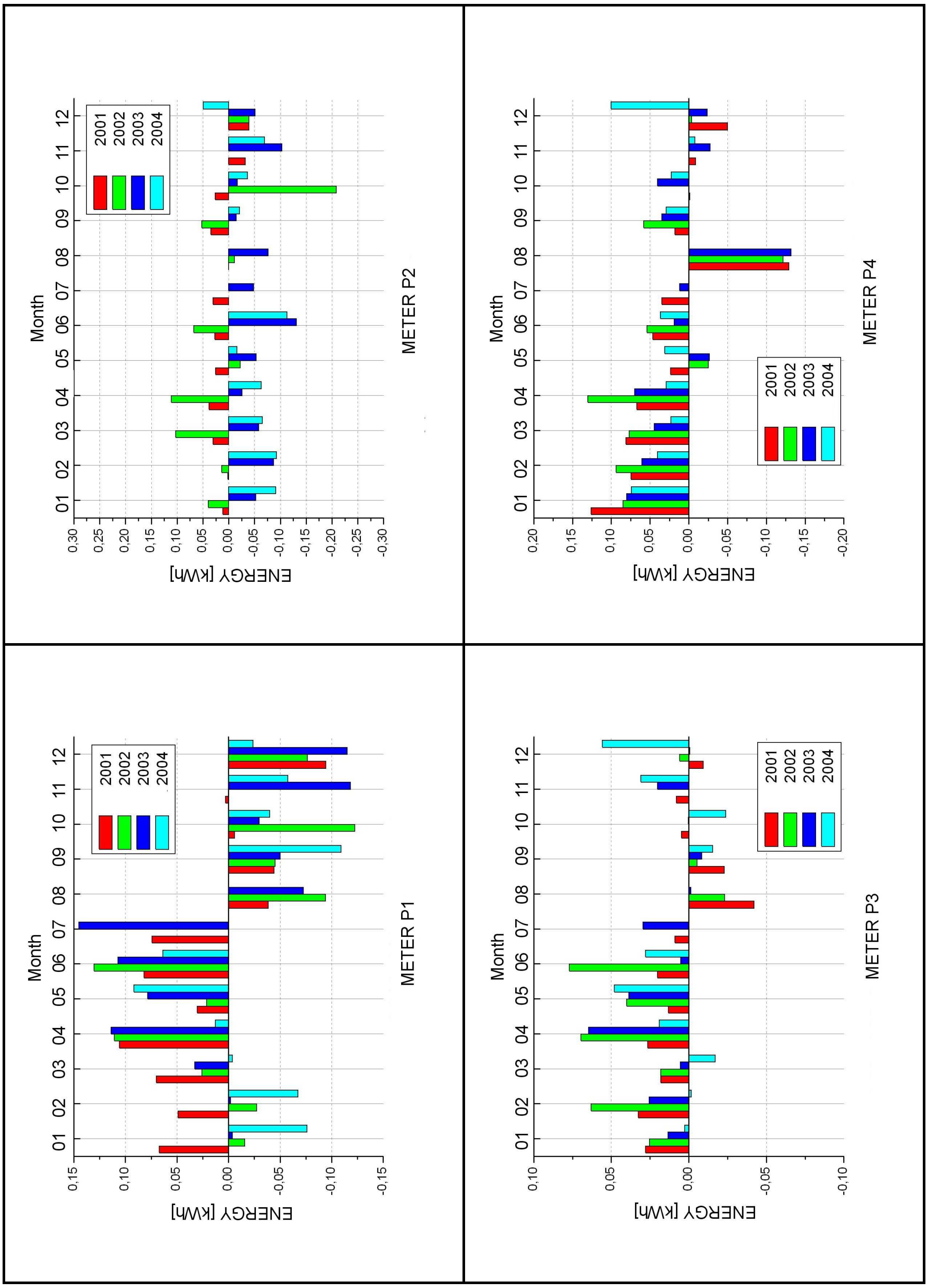


Fig. 8 – Histograms of differences in the average power consumption 15-minute values in years 2001 – 2004, with respect to 2000

The form of data presentation allows for quick comparison of the power consumption and its upward or downward trends in given measurement periods. As is evident in the graphs, the largest changes in the power consumption after installation of the LonWorks system occurred occur in the meter P2 (Dean's office rooms) and P1 results. From the P2 results, the reduction in power consumption can be observed for all months in years 2003 and 2004. For P1 a reduced consumption occurs in winter months with the largest power demand. The two remaining lines — P3 and P4, do not exhibit a considerable reduction in electric power consumption (difference bars above the horizontal axis mean the increase in consumption with respect to 2000), although it can be noted that in subsequent years the positive differences are reduced, particularly in P4 line. For these two meters the negative differences occur only in the summer holiday months. It should, however, be noted that the observed reduction in power consumption in certain lines is not necessarily equivalent to energy savings due to its usage rationalization. Such a conclusion could only be inferred after comparing these data with changes in the number and type of loads connected to the line over a whole measurement period. It can be hypothetically assumed that comparing to year 2000, which was the starting point of the measurement period, the number of loads were increasing. Only assuming the above holds it can be concluded that energy savings did actually occur.

Analysis of energy saving was carried out for all four supplying lines basing on the obtained data and duration of periods with specified level of power consumption in 15-minute intervals during a year. To compare the measurements, the years 2000, 2001 and 2003 were selected because for these years the measurement data were most complete in respective months. After preliminary analysis of data the electric power consumption values were sorted in 0.1 kWh intervals, from 0 to 2 kWh, for the purpose of preparing ordered characteristics. Since the consumption level of 2 kWh during 15 minutes occurred only sporadically, the value of "2 kWh and more" was taken as the highest one on the axis of levels in order to avoid unnecessary extending the vertical axis length and, in consequence, worsening the legibility of characteristics. Assuming the above, characteristics for two meters – P2 and P4 (three characteristics for each meter) were prepared and grouped as shown in figures 9 and 10.

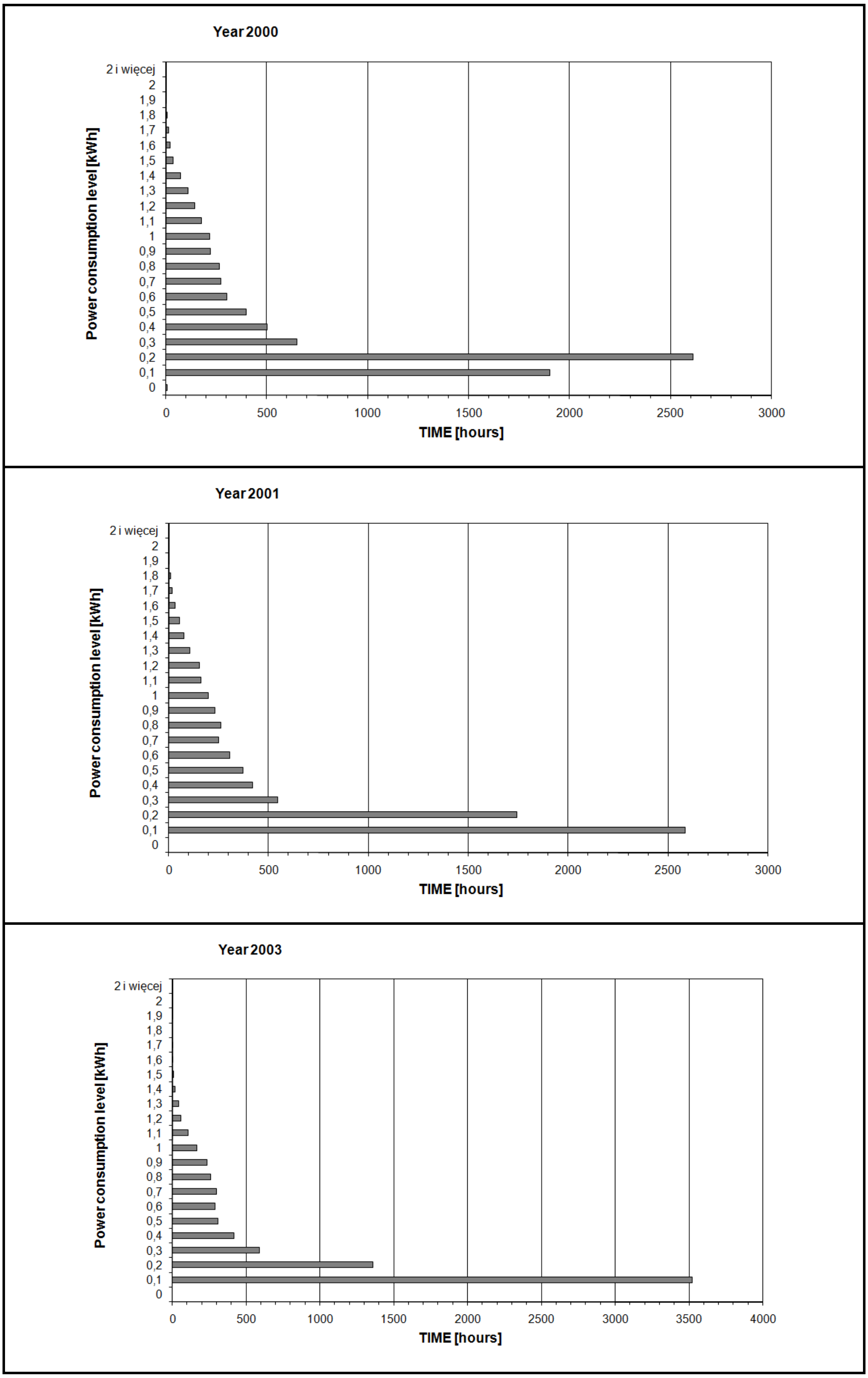


Fig. 9 – Meter P2: ordered characteristics of power consumption at specified levels

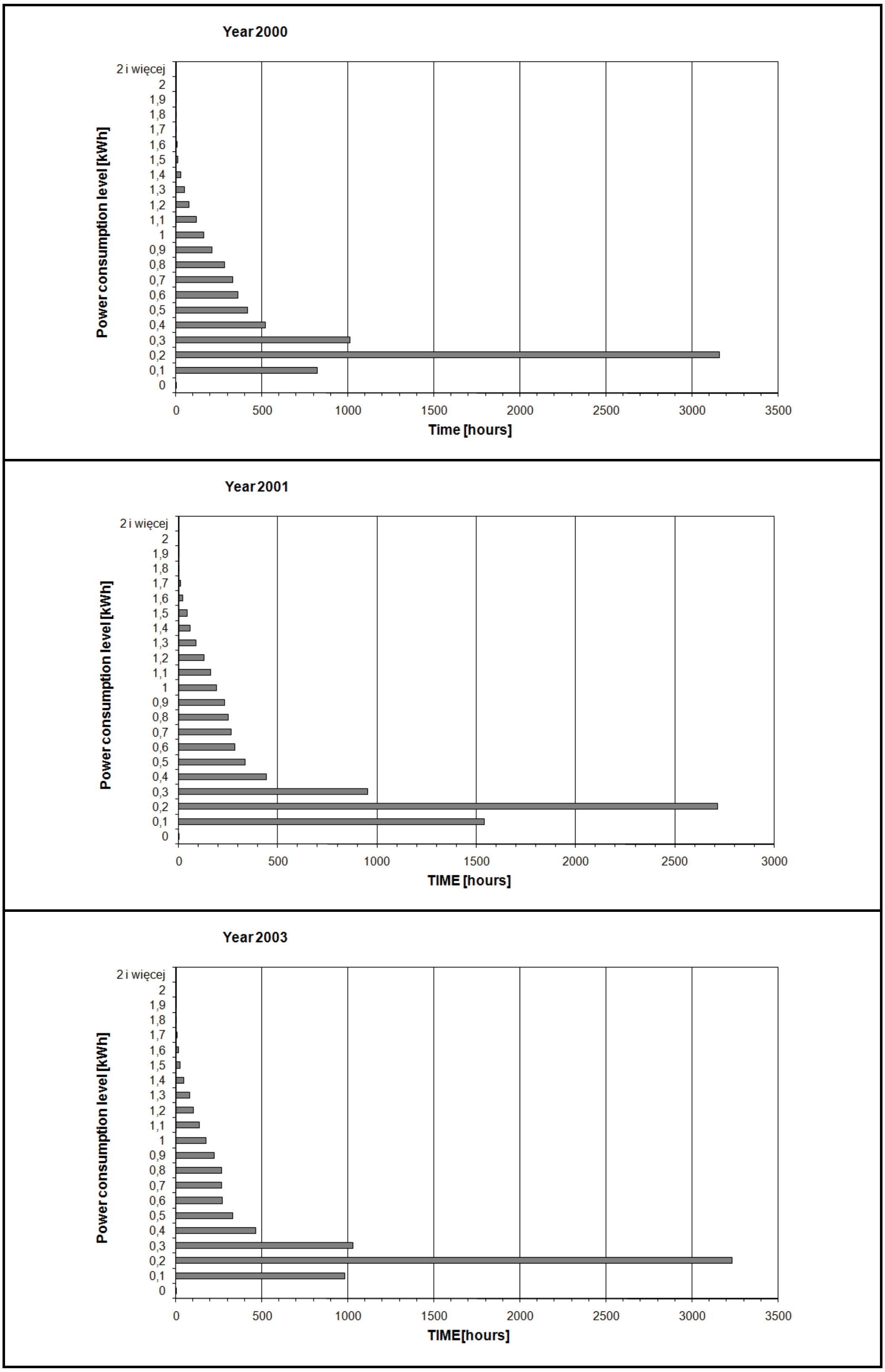


Fig. 10 – Meter P4: ordered characteristics of power consumption at specified levels

Comparing both supply lines it is evident that 15-minute consumption remains at the levels of 0.1 and 0.2 for the longest time during the whole year. It can also be noted that in both cases the dominant level of 15-minute consumption is changing in subsequent years: the time with consumption levels of 0.1 and 0.2 kWh increases gradually while periods with a higher consumption — decrease. In the case of line P2 (faculty staff rooms and dean's office) it should be noted that the time with consumption level of 0.1 kWh/15min compared with year 2000, increases, whereas the time corresponding with consumption levels of 0.2 kWh/15min and higher — decreases. From these facts it can be reasonably inferred that installation of building automation control devices — mainly switching light of and off, may significantly reduce electric power consumption in faculty rooms and administration offices.

A sufficiently long measurement period allows perceiving advantageous tendencies in power consumption, noticeable as a slight reduction in power consumption in subsequent months, as well as extended periods of lower consumption in 15-minute intervals. It should, however, be again enhanced that these trends should not be unambiguously identified with the possible future energy savings. Thus the problem should be addressed taking into account changes in the number and type of loads connected to the supply lines involved. However, without any doubts it can be said that the use of building automation system for on-line data acquisition and analysis of power consumption and power supply parameters (voltage, current, frequency, power factor THD) is purposeful. Such system should employ commercially available meters or power quality analyzers with LonWorks interface. Knowledge of these parameters and quantities enables identification of any irregular conditions or disturbances in the supply network and therefore quick location of their source and monitoring of power supply quality. Considering deregulation of electricity market, where the customer can demand and enforce the quality of power supply from the distribution company, this becomes an issue of particular importance.

Conclusions

Power supply systems and power industry are in contemporary world are significant, if not the most important, sectors of any company, each country and the entire world economy. The continuity of power delivery is of fundamental importance for all customers, particularly for the industry and public sector. That's why the issue of on-line monitoring and measuring of power consumption, electric power consumption, and selected power quality parameters becomes more and more important.

The information and characteristics contained in this paper depict the capabilities of intelligent building systems. Both compared systems exhibit a considerable potential in this area of application. Basing on this research and examining the market offer the LonWorks standard shall be ranked first, though it is not yet fully satisfactory level since the manufactures of LonWorks-enabled equipment offer much more parameters available as the network variables. The manufacturers and RD centers using the KNX standard should therefore respond to the market demand and develop instruments measuring a broader range of power supply parameters and supporting the measurement data transfer in the form of KNX standard telegrams.

The presented applications of intelligent building systems have an opportunity of significant development particularly with prospects connecting them with local networks in buildings or industrial facilities (Ethernet network) and global Internet web. That way the data on building power supply can be remotely analyzed, practically throughout the world.

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