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ORIGINAL PAPER
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PROPOSAL FOR A SOLUTION SUPPORTING A RATIONAL WATER USE IN MULTI-FAMILY RESIDENTIAL BUILDINGS – IMPLEMENTATION IN PROPERTY MANAGEMENT

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ABSTRACT

Motives: Creating a functionality of a software system for managing multi-family residential buildings which could support property managers and encourage households to reduce their water consumption.
Aim: Developing a proposal for a solution supporting a more rational use of water and billing individual households in multi-family buildings for water they use.
Results: The created methodology includes automatic collection and recording of data from water meters in a property management software system, creation of algorithms describing relationships in water meter data, creation of algorithms supporting optimal water use in a property and incorporating the developed solution into the software system. The created algorithms were based on the method of moving average of three consecutive readings which is clear for all users. This enables automatic verification of water use and its visualisation using graphs. The created solution was incorporated into one of the property management software systems used in Poland (IAN24), tested and implemented. The created functionality allows property managers e.g. to estimate future water use, which is important for calculating advance payments towards water bills. It also allows managers to automatically detect various types of anomalies, such as meter failures. In addition, a dynamic method of billing according to the proposed methodology may encourage households to reduce their water consumption and thus reduce the impact for the environment.

Keywords: household water consumption, water resources management, multifamily property, property management, expense forecasting, property management software system

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INTRODUCTION

Continuous social and economic development requires satisfying basic human needs, including supply of water (Sajnóg, 2014). Access to drinking water is a physiological, and therefore a fundamental, need and is the base of the so-called Maslow's hierarchy of needs (1943). Water covers around 70% of the Earth's surface but only about 2.5% of it is fresh water (Yeleliere et al., 2018). Fresh water resources on Earth are estimated at 35 million km³. The global population is growing fast, and estimates show that with current practices, the world will face a 40% shortfall between forecast demand and available water supply by 2030. Furthermore, climate change will worsen the situation by altering hydrological cycles, making water more unpredictable and increasing the frequency and intensity of floods and droughts (The World Bank, 2017). Thus, water scarcity and weather events (floods and droughts) pose threats to prosperity and in extreme cases contribute to increased instability and exacerbation of conflicts (ONZ Resolution, 2015).

In 2015, the UN General Assembly adopted the Sustainable Development Agenda, which sets out 17 Sustainable Development Goals. Goal six: "Ensure availability and sustainable management of water and sanitation for all" stresses the role of access to adequate amounts of clean water as a prerequisite for sustainable development and the promotion of prosperity (McDonald et al., 2014).

Different countries are unequally affected by the scale of the problem. The World Bank regularly monitors, among other things, the level of the Earth's renewable natural resources, including drinking water. According to the 2017 AQUASTAT report, Iceland is the undisputed world leader in terms of the amount of drinking water per capita (507,000 m^3 per capita), Guyana (348,000 m^3 per capita) and Suriname (176,000 m^3 per capita) rank second and third. For comparison, Poland (ranking at 133rd position among 182 countries) has approx. 1.6 thousand m^3 of drinking water per capita. Accordingly, the management of water resources in different countries, depending on national and regional policies, economic size and the awareness of the inhabitants, takes a variety of forms.

According to the World Bank definition, Water Resources Management (WRM) is the process of planning, developing, and managing water resources, in terms of both water quantity and quality, across all water uses. It includes the institutions, infrastructure, incentives, and information systems that support and guide water management. Water resource management also entails water-related risk management, including floods, drought, and contamination. The complexity of relationships between water and households, economies, and ecosystems, requires integrated management that accounts for the synergies and tradeoffs of water's great number of uses and values (The World Bank, 2017).

LITERATURE REVIEW

In the real estate sector, the literature and business practice have identified three basic functions of property management, each having its specific objectives (Thompson, 2015). To a certain extent, each of these functions covers issues related to the supply of energy and water to a property, the calculation and optimization of their use in order to reduce the expenses incurred by the residents, as well as forecasting their future consumption (Figure 1).

The literature has focused mainly on issues related to energy consumption. To better understand the factors affecting energy consumption in facilities, Griffin and others (Griffin et al., 2014) collected energy and meteorological data covering 22 years for 74 sites located throughout the world. They developed a regression model to predict energy consumption for each site. Ullah and others (2018) proposed a Hidden Markov Model based algorithm to predict energy consumption in residential buildings in South Korea using data collected through smart meters. High prediction accuracy of this model gave the authors confidence to further explore its application in building control systems for achieving better energy efficiency. A prediction methodology for energy consumption in residential buildings based

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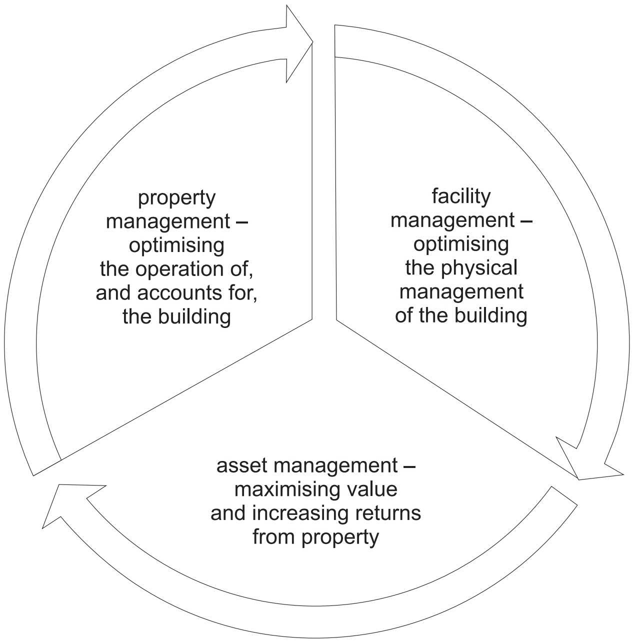

Fig. 1. Basic processes of property management
Source: own preparation based on Thompson (2015).

on deep extreme learning machine was proposed by Fayaz and Kim (2018). The results indicated that in the case of one-week and one-month hourly energy prediction on the given data the performance of deep extreme learning machine was far better than artificial neural network and the adaptive neuro-fuzzy inference system. Ridwana and others (2020) proposed and investigated modelling of building energy consumption by integrating regression analysis and artificial neural network with data classification. The proposed models could potentially be utilized for energy conservation purposes and energy savings in the buildings. Bland and others (2017) introduced the issues related to phase change materials (PCMs) which offer great potential as a latent heat energy storage technique to provide energy efficient systems in new and existing residential buildings. Their study reviewed PCM systems in residential building applications, with focus on their major disadvantages, and concluded with proposals for further development.

Issues related to water consumption, including its forecasting, tend to be addressed in the context of the management of water supply networks. Different types of models are used for water consumption forecasting. Bakker and others (2014) showed that a Heuristic Model and a Transfer/-noise model outperformed a Multiple Linear Regression model when forecasting the one day lead water demand. Mukesh and Adamowski (2015) explored a hybrid wavelet–bootstrap–artificial neural network and also compared its performance with that of standard artificial neural networks (ANN), bootstrap-based ANN and wavelet-based ANN models. Artificial neural networks were also used by Cieżak and others (2015), Romano and Kapelan (2014), Guo and Liu (2018) for forecasting of daily water consumption. As indicated by Somers and Casal (2009), ANNs are efficient in modelling complex linear and non-linear relationships without the need of implicit assumptions. Wałęga and Bergel (2009) evaluated the possibility of forecasting time series of daily household water use in farms with implementation of data mining. To prepare a 10-day water usage forecast, they used the exponential smoothing and the ARIMA method. Al-Zahrani and Abo-Monasar (2015) developed a model to forecast a daily water demand of a city considering meteorological indicators. They demonstrated that time series data need to be combined with other ANN inputs to get a reliable prediction.

In addition, the literature examines various aspects of water consumption by households. Use of water is discussed primarily in the context of its shortage (Klassert et al., 2015) of determinants of residential water demand (Romano et al., 2014), and water consumption pattern and water end-uses in low-income houses (Marinoski, 2014). In turn, Castillo-Martinez and others (2014) describe the results of research in the field of water labels developed to improve the current water billing.

Most of the above-mentioned articles also discuss issues related to management of residential properties in general. Issues related to residential property management are also discussed in some of the recently published papers. Vergara and others (2019) presented the results of an exploratory study about the nature of the management problems in the context of Chilean low-income condominiums. They

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showed the interdependencies between sociocultural, organisational and technical dimensions of the problems specific to the condominiums management and the relevance of the sociocultural variables to performing technical maintenance activities. Huang and Lee (2020) identified possible services that property management companies can provide to elderly residents of apartment complexes in response to changing demographics.

In Poland, the subject of forecasting water consumption is becoming an increasingly important issue in the process of managing residential buildings. This is due to the increase in the prices of water supplied to residential buildings and the resulting growing share of water expenses in household budgets and the need for property managers to collect advance payments towards water bills (2009).

Correct utility billing in a building is an important aspect of work of a residential property manager. Accurate meter data provided as the basis for billing are a guarantee of accurate bills and reduce the risk of complaints. However, water bills usually take into account not only the actual water use, but also the advance payments made by the tenant based on predicted use. Therefore, it was this billing method, which consists of determining average water uses of households and calculating advance payments for water charges on this basis, that was the starting point for creating a functionality which uses a database of archived meter readings and the amounts paid by households for their water usage in previous periods to allow property managers to better match advance payments to the actual demand. The functionality also helps to optimize water consumption through precise control of water expenses.

The aim of this article is to develop a proposal for a solution supporting a more rational consumption of water and billing of households in multi-family buildings. The proposed solution is based on the use of the method of moving average of three consecutive water consumption readings. This method is easy to understand not only for property managers, but also for residents of properties i.e. the persons using water and paying for its use. The created solution was incorporated into one of the software systems used by property managers in Poland, tested and implemented. The functionality enables a prediction of future water consumption, important for calculating advance payments towards water bills, as well as automatic detection of various types of anomalies, such as hydraulic failures, thereby reducing the total water consumption of the property and the corresponding water charges.

METHODOLOGY AND MATERIALS

The functionality supporting a more rational water consumption created for a multi-family property management software was developed in the software environment of the IAN24 property management system. This specific software system is adapted to the management of multi-family residential properties and supports the management process in the area of technical maintenance of the property, organizational, legal, as well as economic and financial services.

When creating the prototype, the method used for testing of the functionality consisted of testing it in the development, then test environment, and ultimately of testing the created prototype with real users. If any errors were detected, the necessary changes were made.

The basic programming language was JAVA, in particular Java EE (Java Enterprise Edition) technology, and a set of accompanying technologies to help create scalable solutions. Data storage was provided by a PostgreSQL database. The user interface was created in JavaServer Faces (JSF) technology using Primefaces framework and support for Omnifaces components. Software development was supported by Bitbucket web hosting, which made it possible to keep a task log and maintain the code in the GIT version control system. Releases of the system, development, test and production instances were run on a dedicated server in a cloud with the possibility to regulate the amount of available resources. Instances were located on the GlassFish application server.

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The methodology of developing the system functionality supporting a more rational water consumption in multi-family residential buildings is illustrated in Table 1.

The software user obtains a financial module for determining the water charges and forecasting the consumption of utilities i.e. of water in the analysed case. With this module, the user can automatically generate the amounts charged for all residential units in the multi-family property. The software leaves the possibility of calculating advance payments manually in cases where the results generated by the automatic model are likely to show excessive errors. Such a case occurs in the event of a change in the manner in which a residential unit is used e.g. in the case of a change of tenant or when the unit is temporarily vacated.

RESULTS

Based on the adopted methodology of developing the functionality supporting a more rational water consumption, new modules were added to the IAN24 software system. At the initial stage of works, an IT tool in the form of an importer was developed to enable automatic collection of data from water meters and its recording in the software system. With this tool, the system allows the user to import data from meters and attribute them to appropriate residential

Table 1. The methodology of developing the system functionality supporting a more rational water consumption

Stage 1.	Automatic collection and recording of data from water meters in the software system
	Automatic collection and recording of water meter readings in the property management software system is carried out based on created algorithms using a data importer. The software system collects the data from a database of meters readings and sends the data to the system server where the readings are attributed to individual households. The report on data import into the software is used to detect and clarify any irregularities.
Stage 2.	Creation of algorithms that describe relationships in data collected from water meters
	Algorithms describing relationships in meter data are created to enable automatic verification of water consumption and visualisation of this data using graphs. The accuracy of water consumption data is verified on the basis of the moving average of 3 consecutive readings. It was assumed that a deviation of up to 30% does not indicate a significant risk of a reading error or irregularity in the operation of the meter. Hence, any deviations above this percentage should be identified and analysed in more detail. This analysis is performed in three steps:
	Step 1. Calculation of the moving average of daily water usage for the previous 7 days. If the difference between a daily water use and the 7-day moving average of the daily water use exceeds 30%, the possibility of a meter failure should be verified. A potential meter malfunction is verified in step 2.
	Step 2. Calculation of the moving average of daily water usage for the previous 30 days. If the difference between the daily water use and the 30-day moving average of daily water use exceeds 30%, the probability of a meter failure is high. The meter failure is finally confirmed or excluded in step 3 below.
	Step 3. The final verification is carried out by comparing the daily water use with the moving average of daily use for the previous 365 days and, if this is not possible, by contacting the owner to explain the reasons for the significant variation in water data. Negative consumption values for any examined period are not allowed.
Stage 3.	Creation of algorithms supporting the optimization of water consumption in a property
	The algorithms created are used for calculating average water uses of individual residential units in a multifamily property and calculating advance payments towards their water use charges. This may contribute to the optimization of water consumption in the property. The water meter readings stored in the software system are the basis for determining the daily, weekly, monthly, quarterly or semi-annual water usage of a given residential unit (depending on the intervals adopted in a given property) to calculate average water uses as the basis for calculating advance payments towards water charges. Based on the calculated average water uses, water charges are automatically calculated for all residential units for their residents to pay in advance.
Stage 4.	Incorporation of the developed solution into the property management software system
	Incorporation of the developed solution enabling automatic collection of readings from meters, analysing the readings and calculating water charges into the software system.

Source: own preparation.

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units, archive readings from removed meters, and upload meter readings from files generated by remote meter reading devices or by the user manually. At the stage of importing data into the software system, the user obtains a tool for efficient previewing and possibly editing the proposed attribution of the data to the information stored in the system. When reading data or archiving meters readings, the system recognizes the meters based on each device's individual number. To attribute a meter to a residential unit, the user can indicate manually the unit to which the meter should be attributed or use automatic attribution by the software system. Any irregularities signalled to the property manager could be subject to clarification to develop of a coherent database based on reports on data import into the system (Fig. 2).

The imported data can be analysed by a system user for all residential units (Fig. 3) or at an individual unit level (Fig. 4) within the selected ranges of readings. This allows the user to initially detect any major deviations that may indicate a reading error, device failure or other failures causing abnormal meter readings. A closer analysis of readings from a particular meter can also be suggested by the software system which indicates a variation of 30% or more compared to the moving average of the last three readings by marking increased use in blue (Fig. 4) and reduced use in green color. Such deviation may be subject to further investigation carried out by the property manager. Normal readings are in standard color (black) and negative values are marked in red. The above rules were established based on property managers' experience and analysis of readings taken daily for a period of 6 months in a property selected for test purposes. The error rate depends on and is proportional to the reading intervals. From the analysis of readings, it can be assumed that the frequency of readings should not be less than once every six months.

Readings from all meters in a multi-family property over a short period of time (less than 1 year) are presented in a graph in Figure 5. In the

Import of meter readings 1 z 55

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Property	B. no.	Unit no.	Meter type	Main meter	Value of a reading	Date of reading	Meter removal date
Wspólnota Mieszkaniowa Kordeckiego 20	20	1	Licznik główny	240056038	0.27	17/04/2018 09:34:18	
Wspólnota Mieszkaniowa Kordeckiego 20	20	1	Licznik główny	240056074	0.26	17/04/2018 09:33:57	
Wspólnota Mieszkaniowa Kordeckiego 20	20	4	Licznik główny	240055387	0.28	17/04/2018 09:34:09	
Wspólnota Mieszkaniowa Kordeckiego 20	20	5	Licznik główny	240056027	7.55	17/04/2018 09:37:17	
Wspólnota Mieszkaniowa Kordeckiego 20	20	6	Licznik główny	240055788	2.19	17/04/2018 09:35:38	
Wspólnota Mieszkaniowa Kordeckiego 20	20	7	Licznik główny	240055783	5.59	17/04/2018 09:35:37	
Wspólnota Mieszkaniowa Kordeckiego 20	20	8	Licznik główny	240055785	8.66	17/04/2018 09:35:44	

Fig. 2. Report on the import of meter readings in a multifamily property
Source: own preparation.

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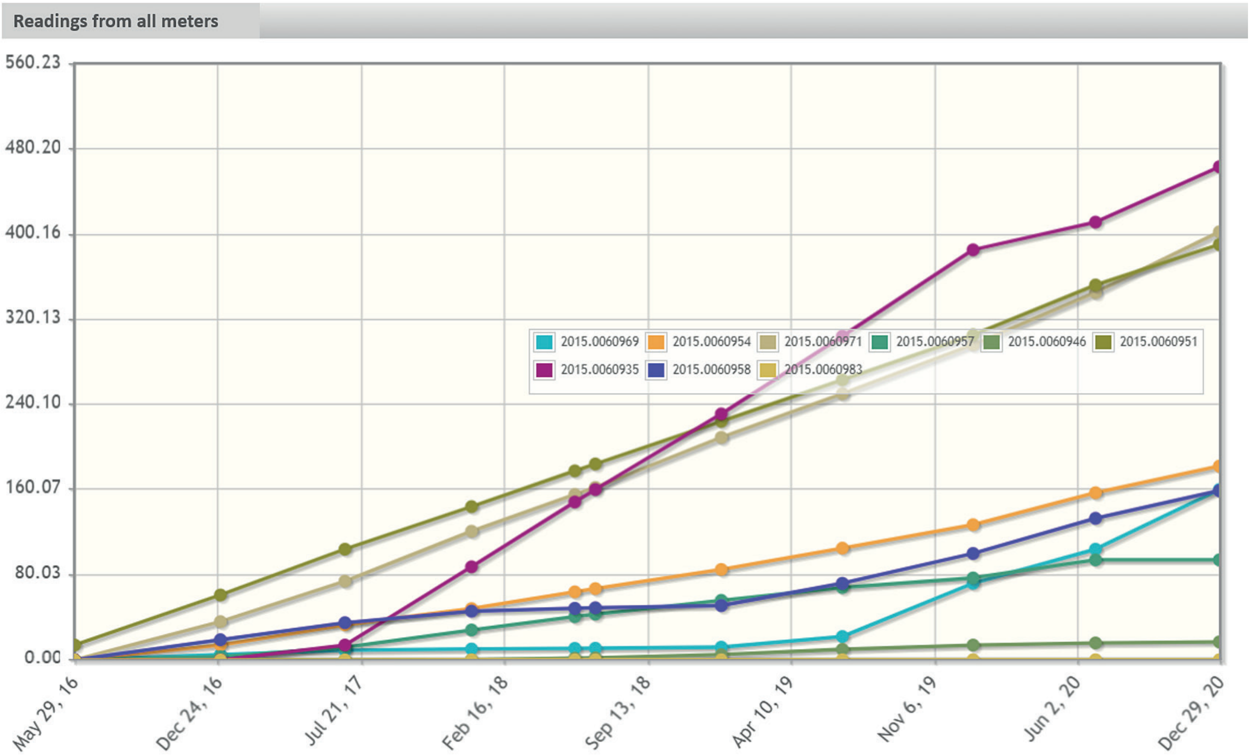

Fig. 3. Readings from all meters in a multi-family building over a long period of time (more than one year)
Source: own preparation.

analysed case, there is a change in the trend of water consumption shown by the meter no. 240056076, which may mean either a reduction in the number of persons living in this unit or illegal tampering with the meter by the its occupiers. Each such case needs to be verified by the property manager.

Verifying the correct functioning of the developed module that enables the analysis of the data uploaded from the meters was performed by:

– checking the meters from which the data were imported;
– checking the calculations of the relationships between readings over time.

Finally, water consumption algorithms were created to calculate average water use and water charges for each residential unit. On the basis of meter readings, the module calculates water consumption in a given period, and then the consumption data are fed to the financial module to calculate average uses and consumption forecasts and to calculate the amount of charges corresponding to a given meter in a residential unit at any given time (there are usually four meters per unit in Poland). For the purpose of the billing process, the developed software functionality enables the user to automatically determine average water use of each unit (average consumption in the current period).

At the same time, the system leaves the possibility to calculate advance payments manually in cases where the results generated by the automatic model are likely to show excessive errors. Such a case occurs in the event of a change in the manner of use of a property e.g. in the case of a change of the tenant or when the residential unit is temporarily vacated.

The correct functioning of the module designed to calculate advance payments for utilities, in particular

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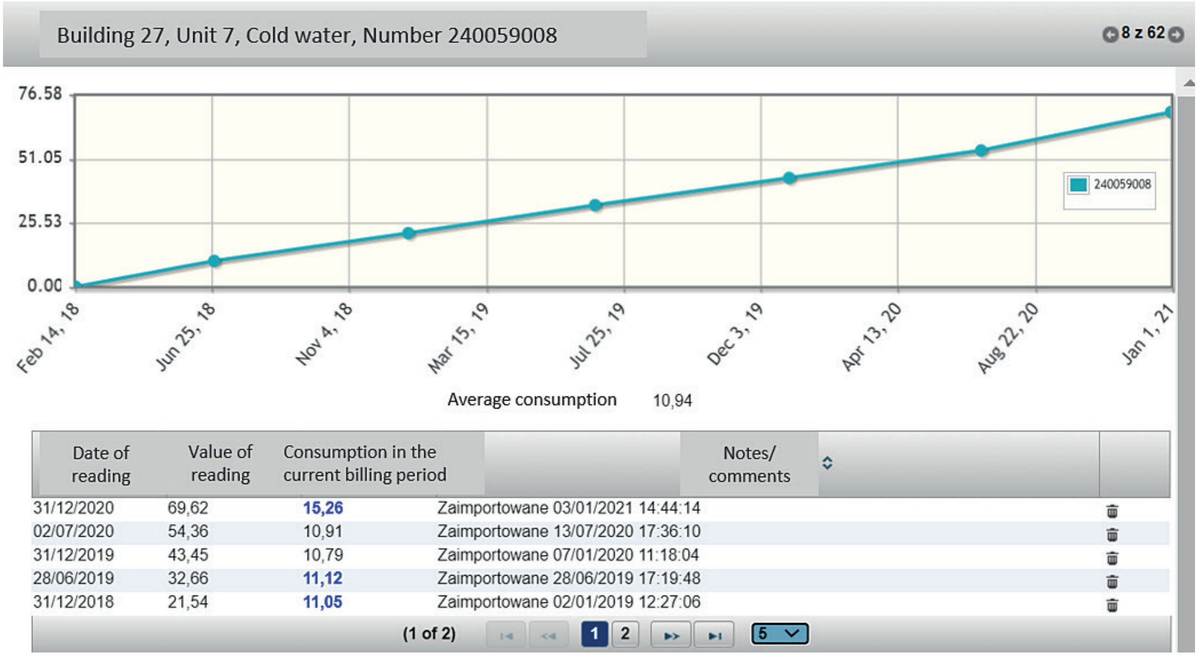

Fig. 4. Graphic visualisation and list of meter readings in a selected residential unit in a multi-family building over a long period of time (more than one year)
Source: own preparation.

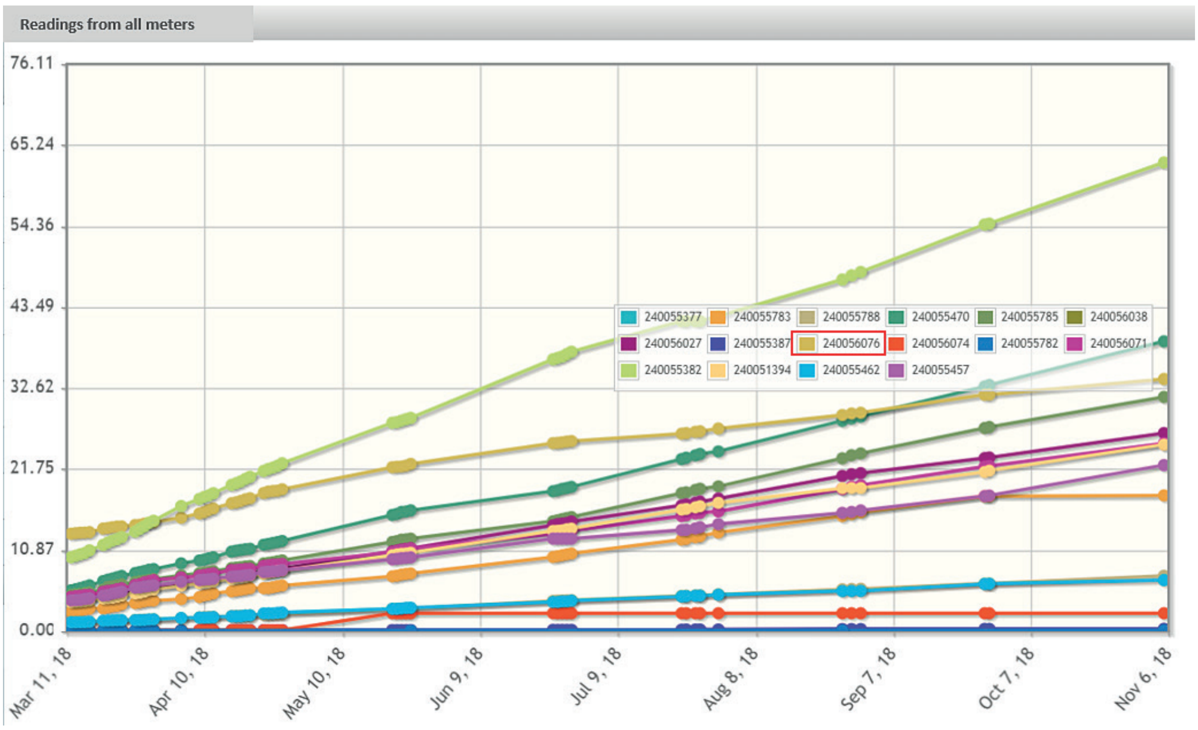

Fig. 5. Readings from all meters in a multi-family building over a short period of time (less than one year)
Source: own preparation.

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water, based on average water uses calculated from verified meter data and on the outstanding balance between the advance payments made and the actual use, was verified in a test in which the following steps were successfully performed:
- verification of advance payments calculated on the basis of average water uses;
- verification of calculations in relation to the actual water consumption and the billed charges.

CONCLUSIONS

The functionality presented in the article created for a software system for managing multi-family residential buildings to support a more rational water consumption, was developed in a four-stage process including: automatic collection and recording of data from water meters in the property management software system, creation of algorithms describing relationships in water meter data, creation of algorithms supporting a more rational water consumption in a property and incorporation of developed solutions into the software system. Key to developing this functionality was the stage of creating algorithms describing the relationships in the data taken from water meters, i.e. illustrating water consumption in specific periods of time. Adopting a moving average of 3 consecutive readings with a deviation of up to 30% appears to be sufficient for the purpose of automatic verification of water consumption in households in a multi-family residential building, assuming that this verification is done in several steps, presented in Table 1. Deviations higher than this percentage threshold should be marked and analysed in more detail to check for a possible reading error, meter malfunction or a hydraulic system failure. Finally, a deviation threshold other than 30% of the three readings' moving average can be adopted after analysing individual cases occurring in a given multi-family residential property. It should be noted that ongoing monitoring of meter readings in multifamily buildings leads to a more rational water consumption in particular due to a more accurate offsetting of advance payments against the actual use and more dynamic calculation of water charges. Due to the occurrence of meter failures or even hydraulic system failures, as well as tampering with meters by some residents to artificially reduce their water charges, verification of meter readings should be one of the important processes in the management of a residential property.

Equally important as the creation of the above-described algorithms was the stage of this functionality's development consisting of creation of algorithms for calculating average water uses and the resulting advance payments towards water charges for individual households. These algorithms are also based on a moving average of three consecutive readings, which is appropriate for reason of its clarity for residents of a property. On the one hand, these algorithms allow a slightly longer period to be taken into account when calculating the advance payments than only the period covered by the last bill and, on the other hand, are not too complicated and thus understandable for the vast majority of residents of the property. The use of more advanced calculation methods allowing a more accurate forecasting of water consumption and thus the water charges, but not easily verifiable by most residents of the property, may lead to allegations of a lack of transparency against the property manager. It should be emphasized that advance payments reflecting trends in water consumption are an important element encouraging a more rational water usage by residents. Automatic calculation of water consumption forecasts for the purpose of determining the amount of advance payments towards water consumption, as well as the dynamic method of billing, according to the proposed methodology, may motivate residents to lower their consumption. Contrary to the currently used method of utility billing, especially the annual one, residents of multifamily properties can quickly see savings in their household budgets if they use water more rationally out of care for their money and the environment.

The created functionality therefore has a pragmatic value. With correct development process, it can be successfully incorporated into any IT system supporting property management.

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