

Analysis of Water Demand in Student Dormitories: An Example of an Unconventional Residential Building

Analiza rozbiórów wody domu studenckiego jako przykład niestandardowego budynku mieszkalnego

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Water demand analysis is a critical tool in the effective management of water supply networks, supporting a wide range of operational and strategic tasks. These include network planning, modernisation efforts, investment decision-making, flow and pressure optimisation, and determining appropriate connection parameters for newly designed buildings. Depending on the objective, such analyses can take various forms, ranging from fundamental statistical evaluations to more advanced studies that incorporate multiple factors influencing water demand. This study focuses on the development and characterisation of a water consumption pattern for a student dormitory in Wrocław. Given the unique nature of dormitory water usage, particular attention was paid to comparing water demand between working days and weekends. By employing a two-means statistical test, the analysis revealed that while the time series representing daily water consumption on weekdays and weekends exhibit distinct characteristics, the overall average daily water consumption remains statistically equivalent. These findings suggest that although students adjust their water usage habits based on their schedules the total volume of water consumed remains stable across different days of the week. Such insights are valuable for water supply network managers, enabling more precise demand forecasting and ensuring efficient system operation, particularly in areas with a high concentration of similar residential buildings.

Key words: water consumption; water consumption pattern; water consumption analysis; water distribution system; water demand.

Analiza rozbiórów wody jest istotnym narzędziem wspomagającym zarządzanie siecią wodociągową, w zadaniach takich jak planowanie prac eksploatacyjnych, modernizacyjnych lub inwestycyjnych, optymalizacja przepływu wody lub ciśnienia, określenie parametrów przyłącza dla projektowanego budynku itp. W zależności od celu, może przyjąć postać podstawowej analizy statystycznej polegającej na opracowaniu wzorca rozbiórów wody i opisanie go jako prostego szeregu czasowego, jak i zaawansowanej pracy uwzględniającej szereg czynników mogących wpływać na pobór wody. Podobnie analizę tę można przeprowadzić dla pojedynczych budynków przy użyciu danych zbieranych przez kilka dni lub tygodni oraz dla całej dzielnicy lub miasta, gdzie pomiary trwają kilka lat. Badania rozbiórów wody przedstawione w tej pracy są poświęcone opracowaniu i opisanie wzorca rozbiórów wody domu studenckiego. Szczególną uwagę poświęcono porównaniu rozbiórów wody w dzień roboczy i dzień wolny (weekend). Przeprowadzona analiza, z wykorzystaniem testu dwóch średnich wykazała, iż te szeregi czasowe mają odmienną charakterystykę, ale średnie dobowe zużycie wody jest statystycznie równe.

Słowa kluczowe: zużycie wody; wzorec rozbioru wody; analiza zużycia wody; sieć wodociągowa; zapotrzebowanie wody.

Introduction

Water flow is one of the critical parameters in water network management. However, water consumption is not of constant value and depends on the circadian rhythm of individual users [13]. From the perspective of water supply network management, an individual's water consumption is difficult to track, so specific objects, such as buildings, districts or even entire cities and regions, are selected for research and analysis. These analyses are performed for various purposes,

so the quality, scope and degree of data processing vary. One of the fundamental documents in Polish legislation regulating water consumption standards is the Regulation of the Minister of Infrastructure of January 14, 2002, on determining average water consumption standards [10]. However, the regulation does not specify the nature of water consumption, but only its amount in a specific unit of time, such as a day or a month. Therefore it is necessary to examine more detailed data to obtain a more accurate picture of water consumption.

One of the more fundamental analyses is the development of water distribution patterns to determine the nature of water consumption, including its unevenness, as described in Dzimińska et al. [4]. The work examined the water consumption of several selected facilities, such as residential buildings, commercial pavilions, schools and a community centre, located in the same DMA zone of Bydgoszcz, Poland. Based on the data obtained, hourly water consumption patterns were developed, and coefficients of unevenness of water consumption were calculated.

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Thanks to the research, accurate information on water consumption was obtained, which is a valuable source of knowledge for scientists, designers and engineers managing the water supply network. This research indicated the differences between the data obtained during measurements and the literature values.

Similar research was carried out in work by Gwoździej-Mazur [5], which examined the water meter size selection by determining the distribution of characteristic flows in the form of the minimum and maximum volume flow of water at the water supply connection during 24-hour and an attempt to determine the number of apparent losses. An ultrasonic water meter with the highest measurement accuracy of R 800 was used for the tests. During the work, the maximum, minimum and average characteristic flows at the water supply connection at specific day hours were calculated for two selected multi-unit buildings. The analysis proved that the share of minimum flows in all water consumption is 50%. Therefore, it is reasonable for the owners of water meters, i.e. water supply companies, to utilize water meters with sizeable metrological accuracy due to the potential apparent water losses.

Da Silva et al. carried out a comprehensive analysis of water consumption. This work examined water consumption recorded in 78 buildings for 25 months [1]. At that time, six models were developed describing the monthly water consumption in the building, the best one with an accuracy of 91%. Thanks to this work, parameters affecting the amount of water consumption in the building were determined, the most important of which is the age of the building, number of floors, area per floor, area per person, number of inhabitants per room and apartment, number of bedrooms, and type of system recording consumption. This study highlights the complexity of the problem of describing and forecasting water use.

Similar research on meteorological factors was presented in Niazmardi et al. [9]. The work analysed data from 5 years obtained from measurements in 566 residential buildings using the Bayesian Estimator of Abrupt Change, Seasonal, and Trend (BEAST) algorithm. In addition to simultaneously examining meteorological factors, the location of measurement points (buildings) was also considered. The results did not indicate any spatial patterns influencing water use. There were also no changes in the volume of water consumption, excluding the initial period of the COVID-19 pandemic. The factors that influence seasonal water consumption are temperature, average wind speed and air humidity.

An important aspect that is constantly developing is forecasting water demand. In 2019, a comprehensive cross-sectional work

was published, illustrating the research directions related to this issue [8]. The article briefly discusses research works using artificial intelligence (AI) models and related algorithms, such as various types of neural networks, regression models, genetic algorithms, fuzzy logic, support vector machines, etc. The authors point out that currently, one of the algorithms cannot be said to be more accurate, but they outperform statistical models in their adaptability. Nevertheless, research work requires a broader description of the models used, as well as considering a more significant number of factors, such as humidity, pressure or temperature, which will significantly increase the complexity of the problem but will also contribute to a greater selection of research methods.

One example of the use of AI in detecting water consumption patterns is the work of Joaquim Leitão et al. [6], which examined the possibilities of analysing water demand by clustering time series. The conducted research indicated that although the accuracy of the clustering performed depends on the target number of clusters and the adopted data preprocessing methods, data clustering allows for a pictorial presentation of the nature of daily water consumption thanks to the algorithms used, which allows for faster detection and description of existing patterns based on scientific methods.

An example of research dealing with the issue of statistical research is the work of Wawrzosek et al. [12]. The work proposed a statistical inference methodology using which an analysis of water consumption was carried out for data obtained from random measurement periods, where there was no significant amount of accurate data, and the measurements were not carried out simultaneously. As a result of the calculations, it was found that long-term measurements of the accumulated values of monthly distributions can provide a lot of information if they are supplemented with a certain number of weekly and daily measurements, with even a much shorter measurement period. The above examples confirm that water partitions and their nature and analysis are complex issues that water companies can use to improve the functioning of the water supply network.

Considering climate change and progressive urbanization, which negatively affect the security and continuity of water supplies [7], increasing knowledge about the water supply network and the recipients who use it may be necessary for the management and operation of the network. This necessity results not only from the scientific research cited but, in many places, also from applicable regulations. The relatively recently introduced Directive (EU) 2020/2184 of the Eu-

ropean Parliament and the Council on the quality of water intended for human consumption aims to limit water losses caused by leaks [2]. A more detailed understanding of the water supply network by examining the water consumption of various entities will contribute to meeting this target.

One of the most accessible solutions is to develop fundamental water distribution patterns for individual groups of consumers, as was done by Dziemińska et al. [4]. For example, a similar analysis can be carried out for a student dormitory, commonly known as an "Akademik" in Polish. A student dormitory may differ from a typical residential facility as students have a slightly different circadian rhythm [11], which is reflected in water demand.

Materials and methods

The research included five student dormitories in Wrocław, supplied with water through two metered water connections. The study aimed to develop a daily water distribution pattern with a 1-hour interval for the student house to analyse and describe it. Water demand patterns were also created and compared for a working day and a day off (weekend). Data for the research were obtained from central water meters belonging to the Municipal Water and Sewerage Company (MPWiK S.A.) in Wrocław.

The data analysis included:

- Determining the accuracy of the readings – verifying whether there were any interruptions in the measurements.
- Calculation of hourly water consumption for both connections,
- Summarizing the obtained hourly data from both connections to obtain a single time series for the tested objects,
- Conversion of hourly data to daily data for detection and removal of outlier observations,
- Development of a weekly consumption pattern with a 1-hour interval,
- Development of a daily distribution pattern with a 1-hour interval for a working day and a day off (weekend).

Calculations, analysis and data visualization were performed in Excel. To conduct a statistical test of means, it was assumed that the distributions of both data sets were unknown. The number of elements in the data-sets was sufficiently large to perform the test. By these assumptions, normal distribution tables were used to read the critical value u_α and the following formula [3] was employed for the test statistics:

$$u = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad (2.1)$$

where u is the test statistics, $\bar{x}_1$ is the mean of water consumption during a weekend, m^3/h , $\bar{x}_2$ is the mean of water consumption during a work day, S_1 is the standard deviation of the sample, which is a set of hourly data demands registered on weekends, S_2 is the standard deviation of the sample which is a set of hourly data consumption registered on weekend days, n_1 is the number of elements in the set containing daily consumption registered during the working days, and n_2 is the number of elements in the set containing daily consumption recorded during weekends. The remaining data, i.e. standard deviations S_1 and S_2 , as well as arithmetic means $\bar{x}_1$ and $\bar{x}_2$, were calculated using the Microsoft Excel function.

Results and discussion

As part of the research, the analysis covered five university student dormitories in Wrocław, providing accommodation for approximately 2,600 inhabitants. Due to the General Data Protection Regulation and the data provision agreement, the dormitory location must remain undisclosed. The measurement period lasted a total of 12 weeks, from November 15, 2022, to February 15, 2023, but 4 weeks had to be excluded from the data analysis as outliers due to the Christmas break at the university from December 23, 2022, to January 9, 2023, and during examination session that started on February 1, 2023. Therefore, approximately eight weeks of measurements were left for further analysis. Full measurement results, in the form of daily consumption, are presented in Figure 1.

No outliers were excluded from the data set during the analysis of the remaining hourly demands. Subsequently, the hourly demand values were aggregated, and the mean hourly consumption was calculated for each day of the week, which is described in Figure 2.

Due to the differences in water consumption between days, the values from working days and from days off were averaged separately. The results of this operation are presented in Figure 3, which also includes the hourly water demand profile for the day with the highest recorded total daily consumption, serving as a reference for the mean values.

A visual assessment of the obtained data allowed us to conclude that the peak water consumption occurs between 22:00 and 24:00, both for holidays and working days, while the lowest water consumption occurs between 03:00 and 05:00. Moreover, in the case of working days, the morning peak in water consumption occurs between 08:00 and 10:00, with the highest water consumption occurring at 10:00. This contrasts with the day off, during which peak times are at 11:00 and 12:00. It is also worth noting that

Fig.1.
Daily water consumption
Rys. 1. Dobowy rozbiór wody

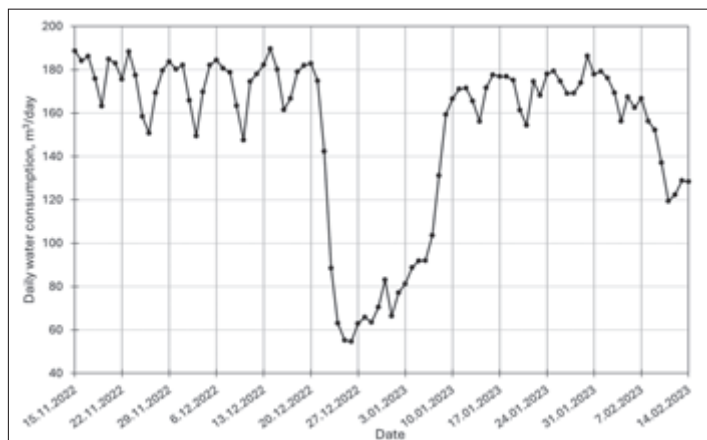


Fig.2.
Mean hourly water demand for each day of the week
Rys. 2. Średni godzinowy rozbiór wody w danym dniu tygodnia

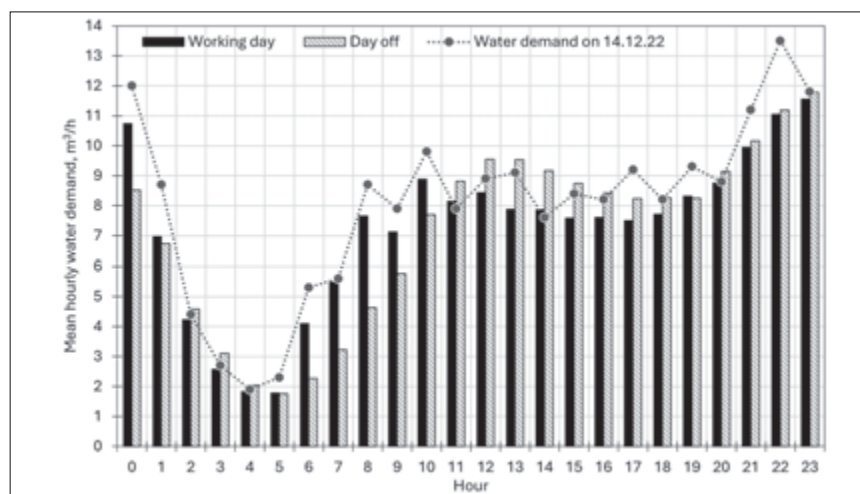
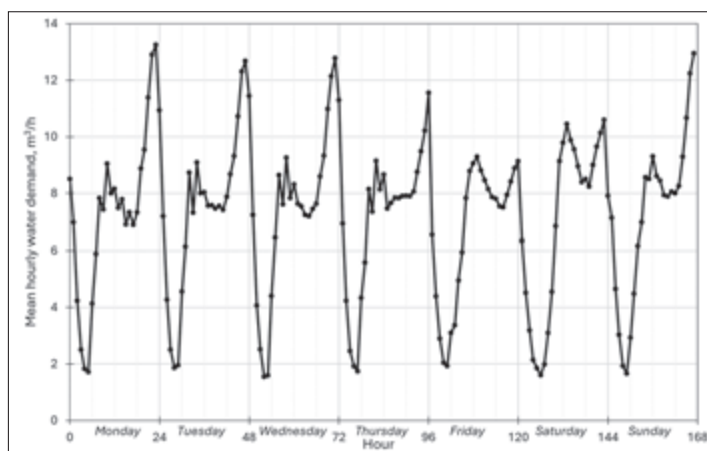


Fig.3.
Average hourly water consumption pattern for a working day, day off and the highest recorded daily demand (14.12.2022)

Rys. 3. Średni godzinowy rozbiór wody dla dnia roboczego oraz dnia wolnego oraz dla dnia z najwyższym zarejestrowanym rozbiorem dobowym (14.12.2022)

the nature of water consumption on a day off is much more regular and predictable. What stands out here is the interval between 05:00 and 12:00. In the case of the working day, we are dealing with irregular consumption, characterized by a sharp increase between 05:00 and 08:00, followed by a decrease in water demand for the next hour and immediately afterwards another sharp increase. In comparison, an almost linear relationship can describe the rise in consumption on a day off between 05:00 and 12:00. The ir-

regular nature of water consumption during a working day from 05:00 to 12:00 is undoubtedly due to the individual schedules of individual students, which starts at potentially equal time intervals, which increases their activity, which translates into higher water consumption in the moments before the start of classes. Based on this, one can assume that most students start classes between 7:00 and 11:00 due to the visible peak. This is generally convergent with the proven student schedule. In contrast, on a day off, when

most students have more freedom to start their day, the variability of water consumption is noticeably lower.

Compared to water consumption in the morning and around noon, water demand in the evening, i.e. between 19:00 and midnight, is similar in volume and nature. Both on a working day and a day off, the increase in water consumption is almost linear, although water consumption on a working day is more irregular. Moreover, it is noticeable that on a working day, the evening increase in water consumption starts earlier, between 17:00 and 18:00. What is also worth noticing is that the peak consumption occurs at a later hour than for a typical residential building. That may correspond to a relatively late student's bedtime, which was described by Semsarian et al. [11] in which the calculated bedtime median was around midnight.

The differences between working days and days off become even more apparent when examining the hourly water consumption on the day with the highest recorded daily demand, which occurred on 14 December 2022 (Wednesday). Although the mean daily consumption on working days is lower, the average hourly consumption on the day off is higher between 11:00 and 17:00. The overall profile of the highest daily demand is largely consistent with the average hourly profile observed on working days; however, at 11:00 and at 14:00, a noticeable dips are present. Those deviations are most likely outliers, potentially resulting from a temporary interruption in water supply, for example due to maintenance activities.

Additionally, the daily water consumption per student was estimated. At peak, the average resident consumed 72,96 dm³/day, while the mean daily consumption across the observation period was 58,63 dm³/day. Both values are significantly lower than the standard specified in the applicable legislation [10], which assumes a daily consumption of 100 dm³ per resident in student accommodation. The reasons for this discrepancy remain unclear, though it is likely attributable, at least in part, to improvements in plumbing systems introduced during the two decades separating the legal regulation and the present study, resulting in notable reductions in water usage.

With regard to various dwelling types outlined in the relevant legislation, the average daily water consumption per inhabitant in buildings connected to both the water distribution and wastewater networks ranges from 60 to 160 dm³/day. This variation depends on access to specific facilities such as a toilet, shower, or heating unit. The values calculated in our study fall within the lower end of this range, despite full access to the aforementioned facilities. This not only indicates a clear distinction between student dormitories and typical residential dwellings but also potentially reflects the previously mentioned changes

in plumbing efficiency and water use habits that have occurred over the past two decades.

Due to the similarity between both demand patterns a statistical test of the two means was conducted – average water consumption on a working day and a day off. It was assumed here that the sample distributions are unknown; therefore, to increase the number of elements in both sets, the test was conducted on the actual recorded hourly consumption values, comprising a total of 383 entries for days off and 1056 entries for working days. This allowed us to meet the assumptions necessary to conduct such a test. The numerical data used to substitute into Eq. (2.1) and the remaining assumptions required to perform the test are included in Table 1.

Table 1. Two means test statistics parameters
Tabela 1. Parametry testu istotności dwóch średnich

Parameter	Value
$\bar{x}_1$	7,15
$\bar{x}_2$	7,26
S_1	3,18
S_2	2,89
n_1	383
n_2	1056
α	0,05
u_α	1,96

Test hypotheses were as follows:

$$H_0: \mu_1 = \mu_2 \quad (3.1)$$

$$H_0: \mu_1 \neq \mu_2 \quad (3.2)$$

The statistical test indicated that with the adopted significance level of 0.05, there are no reasons to reject the null hypothesis H_0 that the average water consumption on a working day and the average water consumption on a day off are statistically equal.

Conclusions

As a result of the research, water consumption patterns were developed for a student dormitory in Wrocław. Their nature was defined and described, particularly the differences and similarities between a working day and a day off. Thanks to the conducted statistical test, it was proved that at the adopted level of significance, despite visible differences in water consumption and slight differences in the size of water consumption, the average hourly water consumption on a working day and a day off are statistically equal.

The results show that although a student dormitory is a residential building, it differs from typical residential buildings. The developed water distribution patterns may prove helpful primarily to industry representatives – designers and specialists involved in maintaining the water supply network. Those patterns can be used in the design of student houses, planned shutdowns of the water supply network in connection with operational works, or implementing these patterns into the hydraulic model examples.

Additional information

the research was carried out using data collected by the Municipal Water and Sewerage Company (MPWiK S.A.) in Wrocław and was obtained under an agreement on providing data for scientific purposes. Under the agreement the data can only be accessed by requesting the data owner. No funding was received to conduct the research.

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