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Research on the Hourly Water Consumption Structure in Rural and Suburban Household

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ABSTRACT

Currently, the character of many households located in rural areas is closer to that of suburban households. The change in the characters of households located in rural areas results in changes in the size and irregularity of water demand, which should translate into a new approach at the stage of water supply systems designing. Therefore, in order to supplement the state of knowledge in this study area, this paper presents the results of the research on the structure of hourly water consumption in two households located in rural areas; the first household had a suburban character, whereas the second one was a typical rural household. The results showed differences in the amount and the distribution of hourly water consumption in the analyzed households. Except on weekends, the average hourly water consumption in rural household (RH) was higher than in suburban household (SH). In contrast, in the rural household, the distribution of hourly water consumption on all days of the week was very similar and the peak water consumption was clearly marking in the morning and in the evening. In the case of the suburban household, a tendency of increased water consumption in the evening was observed, but without clearly noticeable peak water consumption. Moreover, the structure of hourly water consumption in suburban household on Saturday and Sunday was different than on weekdays. The analyzed households were characterized by the highest share of hourly water consumption up to 20.0 $dm^3 \cdot h^{-1}$. In the rural household, both the amount and the distribution of hourly water consumption were determined by water use for additional purposes. In the case of the suburban household, it was shaped by the living needs of the inhabitants.

Keywords: hourly water consumption, rural household, suburban household.

INTRODUCTION

Measurements of water consumption by users taking water from the collective supply systems are important not only because of the necessity to pay for its use. For designers of water supply and sewage facilities, measurements of water consumption are a key source of knowledge about an actual water demand, and thus – the amount of sewage discharged. As the Bergel et al. [2016a, 2016b] or Bugajski and Kaczor [2005] prove, the design guidelines for water consumption standards are overstated and therefore, require updating. Moreover, it must be stressed that the amount of discharged sewage should be determined based on the water use, but only for household purposes. Therefore, it seems to be justified, to measure separately the amount of water used for household purposes and for additional purposes, especially in rural households. As the consequence, the design guidelines and water consumption indicators should be corrected and the generality of their use should be limited. All these actions aim for development of a database on water consumption and then, for using it to perform reliable water demand forecasting. It will help to reduce the design mistakes, especially water supply and sewage facilities oversizing, and thus, it will allow limiting their operational problems and related with them financial costs.

Water consumption by various groups of users is a widely analyzed issue, because it is the only one reliable source of knowledge about the real water demand. In this way, knowing the trends in water consumption, the knowledge base necessary for updating the design guidelines for water and sewage facilities is expanded. In addition to the papers cited above, research on the water consumption can be found in the paper of Pawełek et al. [2015], where the authors analyzed how the water consumption in rural households located in several villages of the Southern Poland has changed over the twelve years. Similar research by Chmielowski et al. [2009] concerned the variability of water consumption in residential buildings in one of the cities of the Southern Poland during a six-year period. Despite the structure of water consumption in daily and weekly cycle has already been quite well known (typical peak water consumption in the morning, in the evening and at weekends), in the case of individual users, the structure of water consumption may differ from each other [Ogiołda and Nowogoński 2018]. Update and modification of design guidelines should take into account not only the decrease in water consumption observed in so many cases [Gorączko and Pasela 2015, Pawełek 2016], but also other factors affecting the water consumption. As the Regulation [2002] determines, the criterion for unit water consumption is the standard of equipping households with water and sewage systems and devices. In reality, water consumption depends on the other factors too. For example, the research of Pasela and Gorączko [2013] prove that there is a relationship between the number of inhabitants living in a given household and the unit water consumption indicator, but the water consumption in a household, is not directly proportional to the number of people living in it. Especially in the case of rural households, a noticeable or often a significant share of water consumption for additional purposes in total water demand should be emphasized [Bergel 2017]. In addition to the water needs for animals breeding or keeping farms clean, additional purposes include water demand for home crops watering. It must be stressed that plants' water needs depend on their natural requirements, as well as the weather conditions changing over the year. In the literature, some studies confirming the correlation of water consumption and air temperature, or more precisely, the increase in water consumption with increasing temperature, may be found [Hotloś 2013, Haque et al. 2015, Dimkić 2020]. Similar conclusions come from the studies on water consumption seasonality in particular months and seasons and the weather conditions typical for them [Pawełek and Kaczor 2006, Bergel et al. 2017]. Investigation on the structure of water consumption in households located on rural areas in countries other than Poland and the factors affecting them, were presented e.g. by Keshavarzi et al. [2006] (Iran), Fan et al. [2013] (China), Basu et al. [2017] (India) or Omarova et al. [2019] (Kazakhstan). On this basis, it can be concluded that in many countries, the issue of water consumption in households on rural areas is still not well–known, compared to the urban areas.

Although both subjected households to a comparative analysis performed in this paper were located in villages, a diverse nature of them (rural household and suburban household), contributed to a different structure of hourly water consumption, also throughout the week. The aim of the study was therefore to supplement the state of knowledge on actual water consumption in households with a different character. Although it might seem that the water consumption, and thus, the amount of sewage discharged in the case of individual users in rural areas does not differ much from each other, it must be noted that the nature of many households located in rural areas has changed in the recent years and now, it is more similar to suburban households than to rural households. Taking this fact into account is especially important at the stage of water systems designing, because the knowledge about an actual water demand should be the basis of rational water supply systems planning.

CASE STUDY

Water consumption research was carried out in two households located in the Southern Poland (Małopolskie Voivodeship). The first of them (SH), was located in the village with small farms, but without agricultural production. In turn, the second household (RH), was located in typical agricultural village, with an intense plants cultivation and animal breeding. It was found that the activities of the SH household were similar to the nature of suburban households; hence, it was named as "suburban household", while the RH household, due to its nature, was named as "rural household". Both subjected households were supplied with water from

the collective water supply and were connected to the collective sewage system. Moreover, they were characterized by the highest class of water and sewage systems and devices equipping. Since total water consumption in households depends on the number of inhabitants and the household nature, household activities and its equipping, etc., it should be noted that in the analyzed period, the suburban household was inhabited by 4–5 persons, the breeding included about twenty domestic birds and the area of watered crops of this nearly 1.5 hectare farm varied from 100 to 1000 m^2. Additionally, the SH household had several vehicles (one car and tractor, two agricultural machines). In turn, the rural household was inhabited by 5–6 persons, the breeding included dozen cattle and pigs and several dozen of domestic birds. The area of watered crops on this 5-hectare farm varied from 100 to 700 m^2. The number of vehicles included two cars, one tractor and five agricultural machines.

MATERIALS AND METHODS

The data used in the analysis come from direct measurements of hourly water consumption carried out simultaneously in both households for a period of one calendar year. Water consumption was measured with vane-wheel single-jet water meters (Q_3 = 2.5 $m^3 \cdot h^{-1}$), installed on water connection (measurement of total water consumption for household purposes of inhabitants and for additional purposes of the farm) and recorded automatically by MiniLog B recorders with frequency once per hour.

As part of the result elaboration, the values of basic descriptive statistics, i.e. minimum (Min), maximum (Max) and average (Avg) were determined for the water consumption recorded in particular hours of the day during the whole research period. Using the same statistics, a distribution of hourly water consumption on particular days of the week was also analyzed. Then, both households were compared based on the average hourly water consumption determined for each day of the week.

In the further part of the paper, histograms of the frequency of hourly water consumption with a specified size were developed for the both households (for the whole research period and for particular days of the week). For this purpose, 22 class intervals with a specified size of hourly water consumption were extracted. The range each of the class interval was 20.0 $dm^3 \cdot h^{-1}$.

RESULTS AND DISCUSSION

Structure of hourly water consumption

The hourly water consumption in the suburban household differed from the hourly water consumption in the rural household, showing at the same time, similar trends in hourly and weekly water consumption as in the urban and rural water supply system analyzed by Ogiołda and Nowogoński [2018]. It was noted that in the whole research period, the suburban household (Fig. 1a) was characterized by a lower average hourly water consumption than the rural household (Fig. 1b). Moreover, the maximum hourly water demand in the RH household equal to 59.0 $dm^3 \cdot h^{-1}$ (at 8:00–9:00), was about 1.5 times higher than in SH household (36.0 $dm^3 \cdot h^{-1}$ at 19:00–20:00). Larger hourly water consumption in the RH household may be associated with regular water use for additional purposes, what is typical for rural households.

In the case of the rural household, both for the whole research period (Fig. 1b) and for particular days of the week (including weekends) (Fig. 1d, f, h, j), the highest average hourly water consumption was noted between 8:00 and 9:00 almost every time (from 53.0 $dm^3 \cdot h^{-1}$ on Friday to 75.0 $dm^3 \cdot h^{-1}$ on Sunday). The second peak of the average hourly water consumption, in most cases, was noted in the evening (between 19:00 and 20:00), with water consumption in the range of 32.0–52.0 $dm^3 \cdot h^{-1}$. Because the RH household had a typical rural character, the increased water demand in the morning and in the evening may be associated not only with the use of larger amount of water for the living purposes of the inhabitants, but also for additional purposes repeated at the same time, regardless of the day of the week (e.g. water use for animal breeding). Moreover, it was observed that the course of the average hourly water consumption in the RH household on particular days of the week was very similar. Thus, it can be concluded that over the week, hourly water consumption in rural households is shaped by the same and unchanging factors. For comparison, for the selected weekdays, Figure 1 shows a distribution of hourly water consumption in the both analyzed households.

The average hourly water consumption in the suburban household (Fig. 1a, c, e, g, i) was more irregular and was characterized by the less noticeable peak hourly water consumption than the

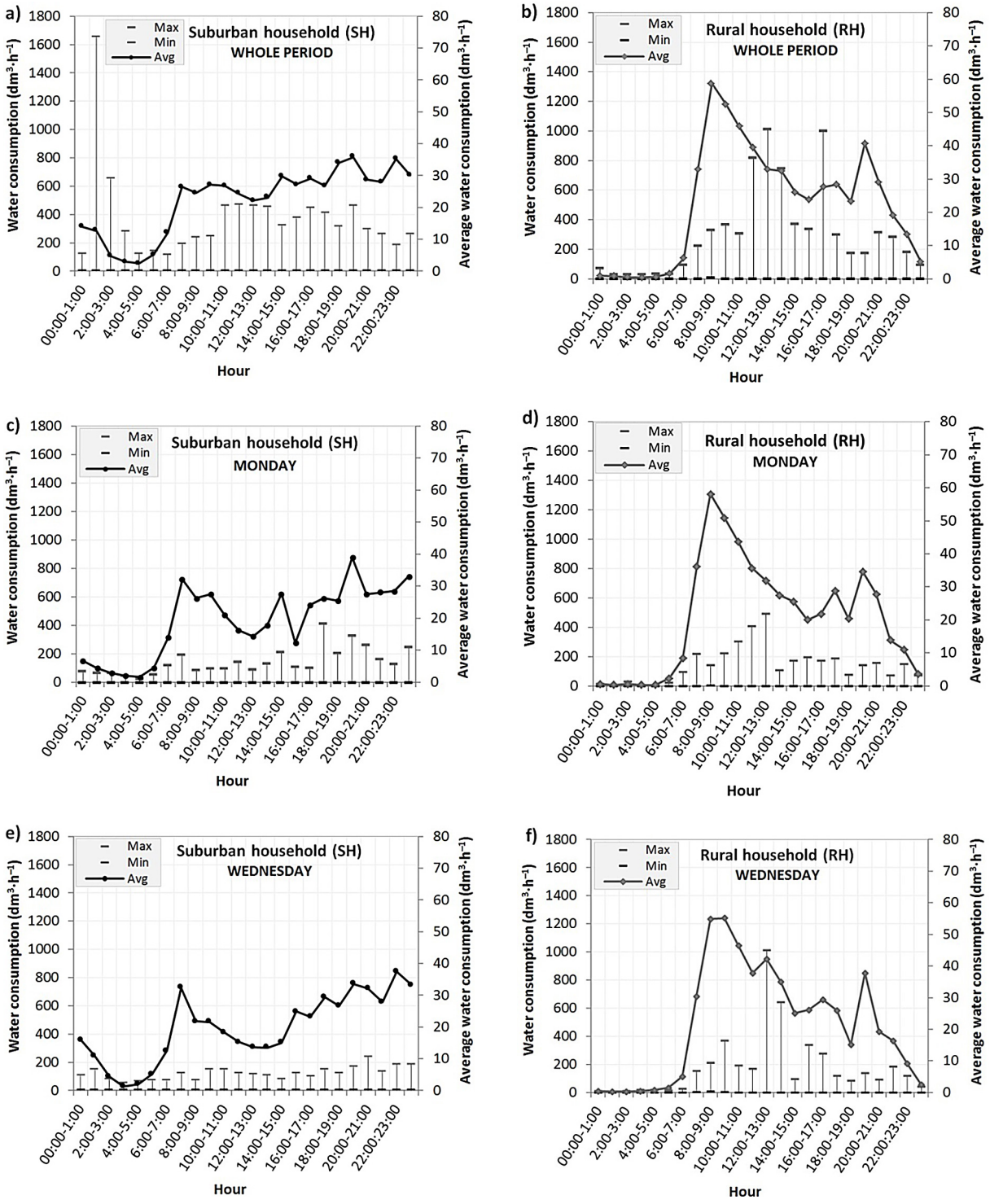

Figure 1. Hourly water consumption in the whole research period and in the selected days of the week in the suburban household and in the rural household

rural household; in the case of SH household, it was observed in the evening (except weekends). When it comes to the above-mentioned irregularity, it can be related, for example, to the evening water consumption peaks that did not always fall on the same hour. It should be noted that in contrast to the RH household, the average hourly water consumption in the SH household on Saturday and Sunday (Fig. 1g, i) was completely different than on the other days of the week (Fig. 1c, e). On Sunday, the peak of water consumption was at noon, and on Saturday, the increased water consumption was from around noon to the afternoon. Moreover, it was noticed that in both analyzed

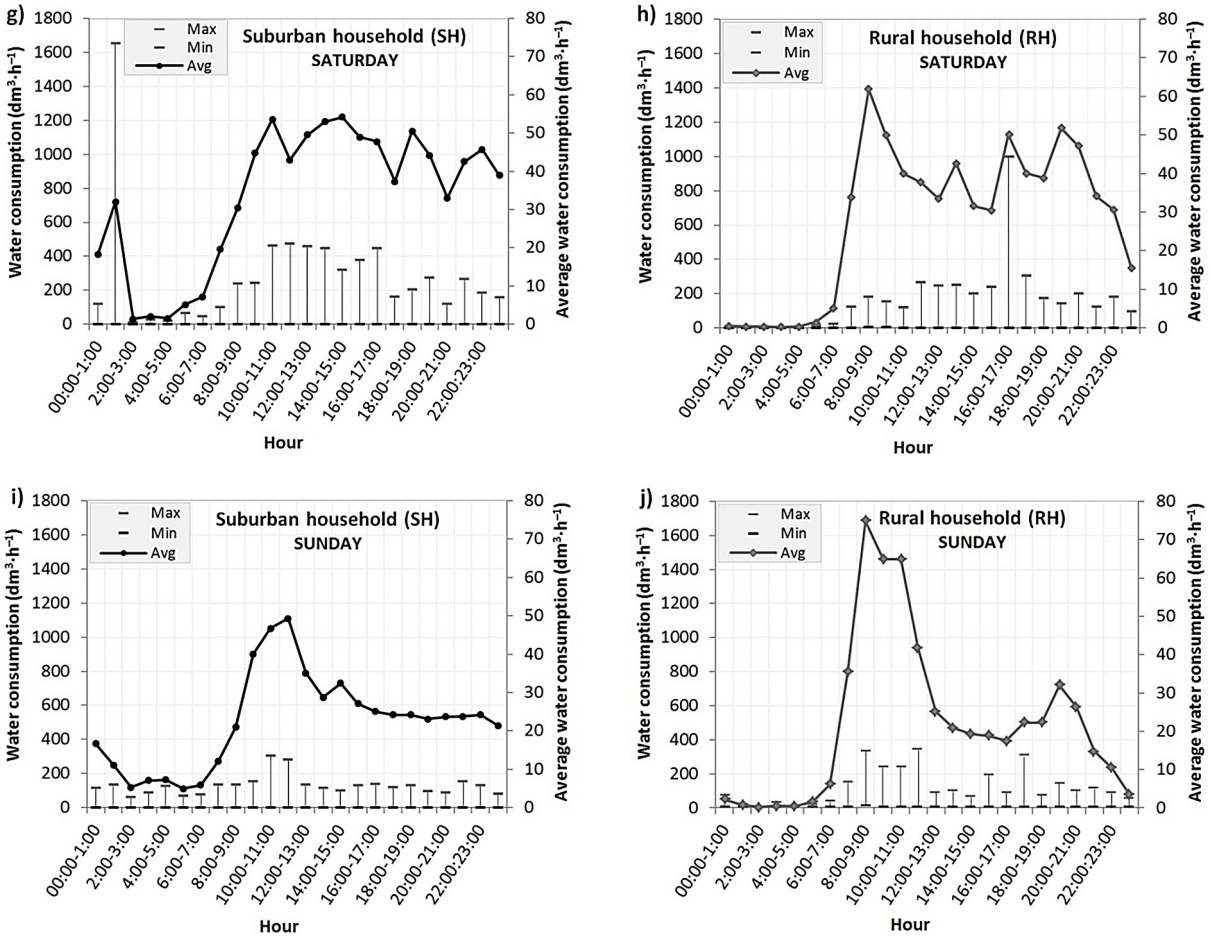

Figure 1. Cont. Hourly water consumption in the whole research period and in the selected days of the week in the suburban household and in the rural household

households, the average hourly water consumption in the peak water consumption hours during the weekend was higher than on the other days of the week. Hourly water consumption in the SH household was related to its suburban nature. Assuming that the share of water consumption in the SH household for additional purposes was small, the distribution of hourly water consumption was shaped mainly by the living needs of the inhabitants and the daily and weekly rhythm typical for such households.

Apart from the differences between the hourly water consumption in the suburban household and in the rural household presented above, another difference is the water consumption at night. Although the water consumption at night was not high compared to the other hours over the day, a tendency of night water consumption was not observed in the rural household. It is difficult to give an unambiguous reason for such a situation, but it can be supposed that it was related to the individual habits of the SH household inhabitants. The other reason for this may be e.g. leaks from the installation or the use of a washing machine using the second energy tariff. Moreover, the results presented in Figure 2 confirm higher hourly water consumption in the rural household than in the suburban household. However, it should be

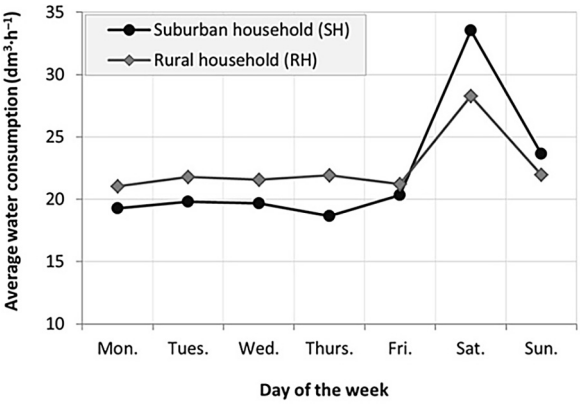

Figure 2. Average water consumption on particular days of the week in the suburban household and in the rural household

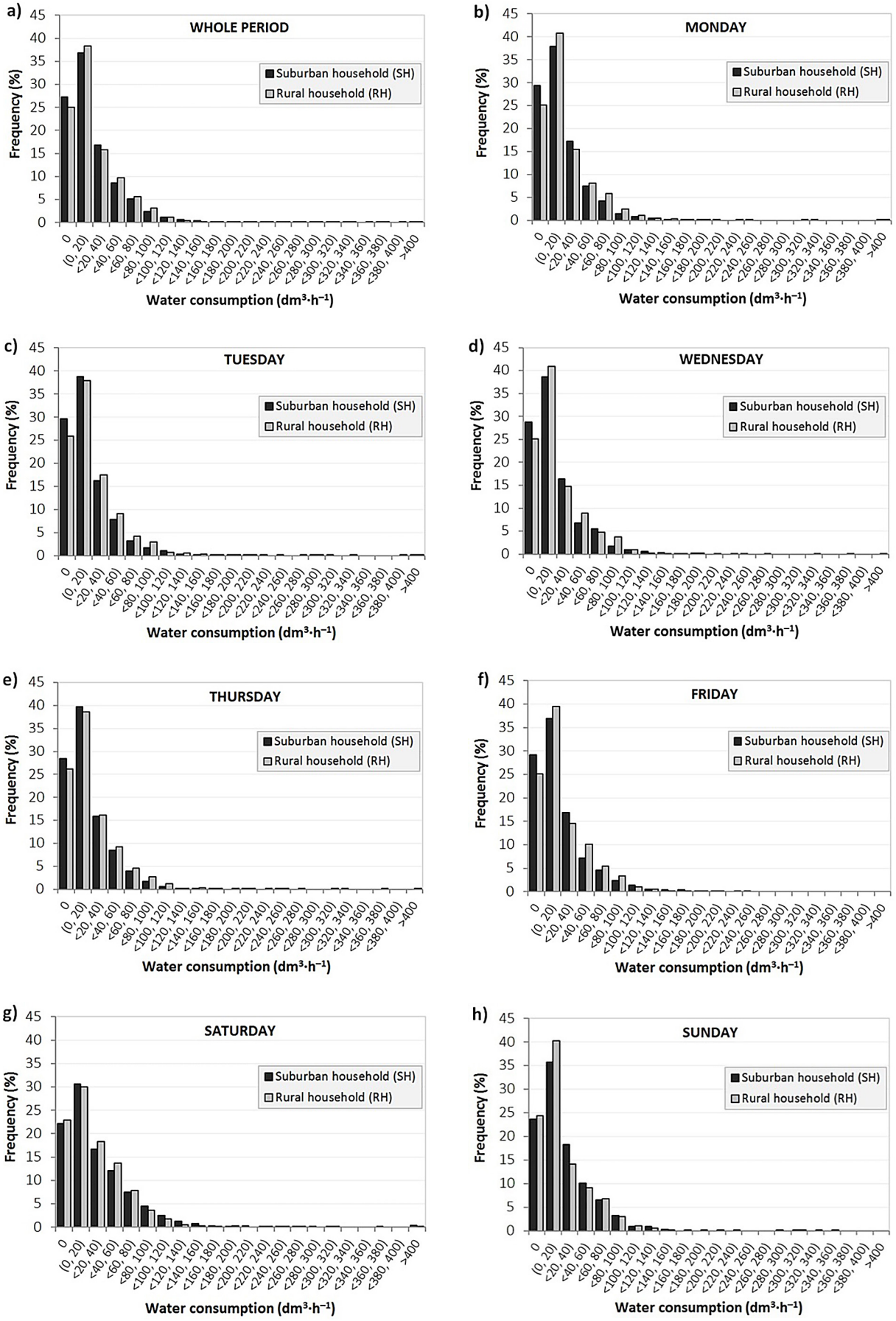

Figure 3. Histograms of the frequency of hourly water consumption in the whole research period and on particular days of the week in the suburban household and in the rural household

noted that it relates to the weekdays solely. On weekends, the average hourly water consumption in the SH household exceeded water consumption in the RH household.

Frequency of the hourly water consumption with a specified size

The histograms of the frequency of hourly water consumption with a specified size (Fig. 3) allowed answering the question: which values of hourly water consumption were the most common in the SH household and in the RH household. It was found that both in the whole research period (Fig. 3a) and on particular days of the week (Fig. 3b, c, d, e, f, g, h), the distribution of the frequency of hourly water consumption with a specified size was similar; thus, the histograms looked similar. In all cases, water consumption up to 20.0 $dm^3 \cdot h^{-1}$ was the most frequent. Above this value, the frequency of water consumption from the successive class intervals gradually decreased, and hourly water consumption reaching the value of several hundred cubic decimeters occurred sporadically. Almost for the whole week (except Saturday), water consumption up to 20.0 $dm^3 \cdot h^{-1}$ represented about 36–40% of hourly water consumption cases. On Saturday (Fig. 3g), this share was slightly lower (30%), because Saturday was a day with higher frequency of water consumption exceeding 20.0 $dm^3 \cdot h^{-1}$ and reaching about 100.0 $dm^3 \cdot h^{-1}$ than on other days. It was observed that in both analyzed households, hourly zero-water consumption constituted a significant part of all hourly measurements (approximately 22–29%). From Monday to Friday (Fig. 3b, c, d, e, f), the suburban household was characterized by a higher share of hours with no water consumption than the rural household, while on Saturday and Sunday (Fig. 3g, h), these differences between the both households became less noticeable. Of course, no water consumption relates especially the night hours, but during the research, it was also observed over the day, which is presented in the Figure 1 as minimum values. The lack of the water consumption over the day is typical for the households the inhabitants of which are away from home. Therefore, it can be assumed that such a situation occurs more often in suburban households on weekdays, because the inhabitants work outside the household, and often, away from the place where they live. This assumption is confirmed by the hourly water consumption measurements in the suburban household. In general, throughout the whole research period, it was observed that the frequency of water consumption in the amount of up to about 100.0 $dm^3 \cdot h^{-1}$ was higher in the RH household. In turn, the SH household was characterized by a higher frequency of water consumption in the amount of between 100.0 $dm^3 \cdot h^{-1}$ and 180.0 $dm^3 \cdot h^{-1}$ (Fig. 3a). Hourly water consumption above 260.0 $dm^3 \cdot h^{-1}$, reaching the value of even 1000.0 $dm^3 \cdot h^{-1}$, was also observed in the both analyzed households, but as single cases. As it can be supposed, in the rural household, it was associated to a large extent with the use of water for additional purposes other than animal breeding. In the case of the suburban household, it was probably related to the daily household activities, domestic works or habits of the inhabitants etc., which are typical for individual days of the week and hours of the day.

CONCLUSIONS

The research on water consumption in two households located in rural areas made it possible to write the following statements and conclusions. A different distribution and the amount of hourly water consumption in rural household and in suburban household were observed. From Monday to Friday, the average hourly water consumption in suburban household was found to be lower than in rural household. It resulted from the lower share of additional purposes and the limited activity of the suburban household inhabitants on those days. The course of the average hourly water consumption in rural household on individual days of the week (including weekends) was very similar. Almost every day, the first peak of the water consumption was in the morning (at 8:00–9:00), and the second peak, was in the evening (at 19:00–20:00). The average hourly water consumption in suburban household was more irregular than in rural household. Although on weekdays, the highest water consumption in suburban household fell on the evening hours, it was not as clearly visible water consumption peak as in the rural household. Contrary to the rural household, the average hourly water consumption in suburban household on Saturday and Sunday was completely different than on the weekdays. Both in rural household and in suburban household, the most frequent was hourly water consumption up to 20.0 $dm^3 \cdot h^{-1}$ (about 36–40%). In the rural

household, the highest water consumption certainly resulted from the water using for additional purposes other than animal husbandry. In the case of suburban household, it was probably related to the typical for individual days and hours of the day household activities or domestic works as well as habits of the inhabitants. Constituting a significant part (about 22–29%), no water consumption in particular hours, was more noticeable in suburban household and did not concern only night hours. The lack of the water consumption over the day is typical for the households the inhabitants of which are away from home. The analyzed suburban household may be considered to be such a household. The distribution and the amount of hourly water consumption in rural household were shaped mainly by the unchanged water demand for additional purposes (especially animal breeding), in constantly repeating times of the day, regardless of the day of the week. In turn, the structure of hourly water consumption in suburban household indicates that it was shaped mainly by the living needs of the household's inhabitants. Currently, the character of many households located in rural areas is more similar to suburban households. It translates to the characteristic structure of water consumption, different than in the case of typical rural households. The change of the character of households located in rural areas results in changes in the size and irregularity of water demand. It should translate into a new approach, especially at the stage of water supply systems designing.

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