Water load pattern in a production hall

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Abstract. The actual volume of water consumption in the various industrial halls is very diverse. Many factors have an impact on that value, depending on the demand for: domestic, fire-fighting, technologically specific target and other purposes. The demand for domestic water in the production hall is primarily due to the use of showers, wash basins and flush toilets. Workplaces should be appropriately equipped with hygienic and sanitary facilities, depending on its degree of soiling, type of work and gender.
The water flow is relevant for dimensioning the water supply system including the diameter selection of the water pipes. Criterion for selection of the diameter is the flow velocity of the water which varies depending on the manufacturer's guidelines, the material used and the law.
The article analyses the dynamics of load pattern of hot water in industrial halls. The methods of flow calculation in production halls based on an analysis of patterns available in literature and the water flow velocity criteria is discussed. The results of the research of the dynamics of water load pattern in a production hall located in Wroclaw is presented and discussed.

1 Introduction

The actual volume of consumed water in various hall-type buildings is very diversified. Water consumption is dependent on various factors and is used for the following purposes:

- domestic water (hygienic/sanitary and cleaning purposes),
- fire-fighting,
- industrial process water,
- additional purposes (e.g. irrigation/watering).

Water for domestic purposes in a hall is mainly used in showers and washbasins and also for the flushing of toilets. The total volume of water (hot and cold water together) consumed in workplaces can be defined on the basis of the Regulation of the Minister of Infrastructure on determining the average water consumption standards [1] and the Announcement of the Minister of Economy, Labour and Social Policy on general work safety regulations [2]. However, the water amount for hygienic purposes stated in Announcement [2] is 30 litres higher in workplaces where shower use is obligatory and two times higher for remaining workplaces as compared with the water volume given in the Regulation [1].

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The bibliography [e.g. item 3] provides consumption figures for domestic hot water in industrial washrooms and baths with showers which may be used to size the hot water preparation equipment.

According to the Regulations [2 and 4], the hygienic/sanitary rooms in workplaces should be equipped depending on the degree of soiling, type of work and gender. The Announcement [2] details the number of sanitary appliances depending on the kinds of soiling and the necessity of shower usage. If the number of persons staying in a specific storey is less than 10, it is admissible to locate the WC on the nearest storey, higher or lower, and to provide a common WC for men and women [2,4]. What would be additionally noted is the number of hot water draw-off points according to [5] should be determined so as the washing time of workers for the most numerous shift is no longer than 30 minutes. According to the type of work to be done in hall-type buildings, it may be necessary to install special hygienic/sanitary appliances. If the workers are exposed to leg soiling, then footbath appliances [2] in washing rooms should be provided. Safety showers and eyewash fountains are used where accident hazard exists due to contact with flammable, toxic, radioactive or corrosive substances, or burn from flame and hot steam. They are installed at a distance of not more than 20m from workstations and shall be reliably supplied with unheated water at a temperature, as currently indicated, of 15°C [6] independently of the atmospheric conditions. The regulations stated in [2, 7-11] specify the necessary emergency appliances to be used in various workplaces.

2 Designing of water supply installation

The proper operation of a water supply system depends on a series of appropriately selected elements, namely:
- water source and intake,
- sanitary appliances in rooms,
- standard outflow from sanitary appliances,
- design flow rate of water,
- pressure before draw-off point,
- velocity of water flow in the system,
- pressure required in the system,
- materials used to make the system,
- type and selection of water meter,
- protection against secondary water pollution,
- method of system disinfection,
- operation of the hot water circulation system,
- insulation of piping.

2.1 Calculation of water flow

Hydraulic calculations of water conduits consist of:
- determining the diameters of conduits,
- calculating pressure losses at a specified water flow rate,
- determining the minimum pressure ensuring water supply continuity to the most unfavourable located draw-off point in the system.

In order to make hydraulic calculations, it is necessary to determine the design water flow rate. This parameter is reliable not only for the selection of the conduit diameters but also for equipment in the water supply system. When it is calculated properly, the correct operation of the water supply system is ensured. Hall-type production buildings, where a substantial number of workers are engaged, are not typical facilities and the method used to calculate the design water flow rate is not explicit. In production halls the demand for water is equal during the year, whereby the hot utility water demand has periodical peaks when showers and washbasins are used at the end of each work shift and a maximum demand occurs in whole installation working period. The periods of installation usage are dependent on the number of working shifts and working/holiday days during a year [12-14].

The common relations stated in the PN-92/B-01706 standard [15] provide the basis for determining the design water flow rate. However, although according to the Polish Committee for Standardization this standard bears the status of “withdrawn without replacement”, it is cited in the amendment of the Regulation of the Minister of Infrastructure and Development of 2018 on the technical conditions to be met by buildings and their location [4] as concerns, among other things, the general rules of sizing the water supply conduits and determining the design water flow rates in residential buildings, office buildings, hotels and department stores. For water supply systems in other facilities, according to the standard [15], a formula for determining the design water flow rate should be selected by analogy with the way of using the system by its users. It is not easy and obvious to find an analogy between using water supply system in typical building specified in the standard [15] and that used in a production building. However, the standard allows using other calculation methods, if they are technically justified. In the bibliography, for instance in [16], there are equations which enable finding design flow rate in the water supply systems of schools and hospitals. The equations for these facilities were taken from German standard DIN 1988 [17], and they supplement the equations from PN [15]. Examinations and analyses [18] proved that for facilities with a large water demand, like some hall-type production buildings, where a considerable number of persons are engaged, it is rational to use the equations of design water flow rate for schools.

Table 1. Water flow acc. PN-92/B-01706 [15] and DIN 1988 [17].

Type of building	**Formula**	**Note**	**Water flow rate**	
			Σq_n=1.54 dm^3/s	**Σq_n=40 dm^3/s**
Residential buildings	$q = 0.682(\Sigma q_n)^{0.45}-0.14$	$0{,}07<\Sigma q_n\leq 20$ dm^3/s ; $q_n<0{,}5$ dm^3/s	0.69	-
	$q = 1.7(\Sigma q_n)^{0.21}-0.7$	$\Sigma q_n>20$ dm^3/s ; $q_n\geq 0{,}5$ dm^3/s	-	2.99
Office buildings	$q = 0.682(\Sigma q_n)^{0.45}-0.14$	$\Sigma q_n\leq 20$ dm^3/s	0.69	-
	$q = 0.4(\Sigma q_n)^{0.54}+0.48$	$\Sigma q_n>20$ dm^3/s	-	3.41
Hotels and departmant stores	$q = (\Sigma q_n)^{0.366}$	$1<\Sigma q_n\leq 20$ dm^3/s ; $q_n>0{,}5$ dm^3/s	-	-
	$q = 0.698(\Sigma q_n)^{0.5}-0.12$	$0.1<\Sigma q_n\leq 20$ dm^3/s ; $q_n<0.5$ dm^3/s	0.75	
	$q = 1.08(\Sigma q_n)^{0.5}-1.83$	$\Sigma q_n>20$ dm^3/s ; hotels	-	5.00
	$q = 4.3(\Sigma q_n)^{0.27}-6.65$	$\Sigma q_n>20$ dm^3/s ; departmant stores	-	4.99
Hospitals	$q = 0.698(\Sigma q_n)^{0.5}-0.12$	$\Sigma q_n\leq 20$ dm^3/s	0.75	-
	$q = 0.25(\Sigma q_n)^{0.65}+1.25$	$\Sigma q_n>20$ dm^3/s	-	4.00
Schools	$q = 4.4(\Sigma q_n)^{0.27}-3.41$	$1.5<\Sigma q_n\leq 20$ dm^3/s ; $q_n<0.5$ dm^3/s	1.53	-
	$q = \Sigma q_n$	$\Sigma q_n\leq 1.5$ dm^3/s	-	-
	$q = -22.5(\Sigma q_n)^{-0.5}+11.5$	$\Sigma q_n>20$ dm^3/s	-	7.97
		Minimal value	0.69	2.99
		Maximum value	1.53	7.94

Table 1 summarizes the equations and figures of water flow rate for $\Sigma q_n = 1.54$ dm^3/s and $\Sigma q_n = 40$ dm^3/s. The value $\Sigma q_n = 1.54$ dm^3/s used to compare the values of water flow is equal to the value Σq_n for the hall-type building under consideration, as outlined in Chapter 3.

In 2012, the DIN 1988-300:2012-05 [19] standard was published where the general formula for determining the water flow rate for the condition $0.2<\Sigma V_R<500$ is of the form :

$$V_s = a\,(\Sigma V_R)^b - c \qquad (1)$$

where V_R is the design outflow for individual draw-off points, and the coefficients a, b, c are dependent on the type of building and are given in Table 2 [19, 20]. The table also provides the calculated water flow rates determined for $\Sigma V_R = 1.54$ dm^3/s and $\Sigma V_R = 40$ dm^3/s. If we use the formula (1), there is no division depending on the value of ΣV_R, as it was the case for formulae given in Table 1. It is worth mentioning that the standards [19] give lower values of the individual outflows for a washing machine (0.15dm^3/h) and dishwasher (0.07dm^3/h) than those used until now according to PN-92/B-01706 [15]. It is essential for designing water supply systems in residential buildings [20]. Such appliances are not commonly used in industrial hall-type buildings.

Table 2. Parameters for the calultion of water flow acc. DIN 1988-300:2012-05 [19].

Type of building	**Parameter**			**Water flow rate [dm^3/s]**	
	a	**b**	**c**	**$\Sigma V_R = 1.54$ dm^3/s**	**$\Sigma V_R =$ 40 dm^3/s**
Residential buildings	1.48	0.19	0.94	0.67	2.04
Hospital	0.75	0.44	0.18	0.73	3.62
Hotel	0.70	0.48	0.13	0.73	3.98
School	0.91	0.31	0.38	0.66	2.48
Public building	0.91	0.31	0.38	0.66	2.48
Apartments for disabled and elderly	1.48	0.19	0.94	0.67	2.04
Care home	1.4	0.14	0.92	0.57	1.43
Minimal value				0.57	1.43
Maximum value				0.73	3.98

As it results from comparisons of calculated water flow rates in Tables 1 and 2, the values can differ from 170% for a small sum of standard outflows up to 457% for a large sum of standard outflows.

2.2 Water flow velocity

If the formula for design water flow rate is properly selected, it allows choosing the diameters of piping, hence to ensure water flow velocity ensuring the proper operation of the system. It is essential to design the system considering the recommended velocities according to PN [15], or the manufacturer's indications, as it directly affects the following:

- degree of pipe corrosion,
- noise level of system operations,
- hydraulic hammer,
- line and local pressure losses in the system,
- development of biofilm which, along with temperature and stagnant water, is of crucial importance for preventing Legionella bacteria growth and their control [21].

Admissible maximum velocities of water which are decisive criterion in selecting the diameters of piping are, according to PN [15], are as follows:

- up to 1.5 m/s in connections from riser to draw-off points and in risers of water supply system,
- up to 1 m/s in main distribution lines and home service pipes.

Manufacturers of plastic pipes specify the following admissible velocities:

- for risers and service lines to draw-off points – up to 2.5 m/s,
- for main distribution lines – up to 2 m/s,
- for water supply service pipes – up to 1.8 m/s.

The requirements for admissible velocities in system conduits acc. to DIN [19], depending on the duration of maximum flow rate and local resistances of the fixtures on the plot, are specified in Table 3.

Table 3. Water flow velocity acc. DIN 1988-300:2012-05 [19].

Type of water-pipe	**Water velocity [m/s]**	
	Duration of calculated flow water < 15 min	Duration of calculated flow water ≥ 15 min
Water supply connection	2.0	2.0
Sections in the installation with elements with resistance coefficient $\zeta<2.5$	5.0	2.0
Sections in the installation with elements with resistance coefficient $\zeta\geq2.5$	2.5	2.0

3 Research of water load pattern in production hall

Examinations were carried out for the flow rate and velocity of water in a production hall in Wroclaw. The work in the hall is of low soiling potential; the bathrooms are equipped with 22 washbasins to wash one's body after their shift; no showers are installed. Most workers are women. There are three shifts, seven days a week. About 350 people work during the morning shift, from 6:00am to 2:00pm, about 250 people during the day shift from 2:00pm to 10:00pm, and about 100 people during the night shift from 10:00pm to 6:00am. Figure 1 shows the dynamics of hot water consumption for seven days from Wednesday to Tuesday. A considerably larger water demand is observed after the first shift on weekdays.

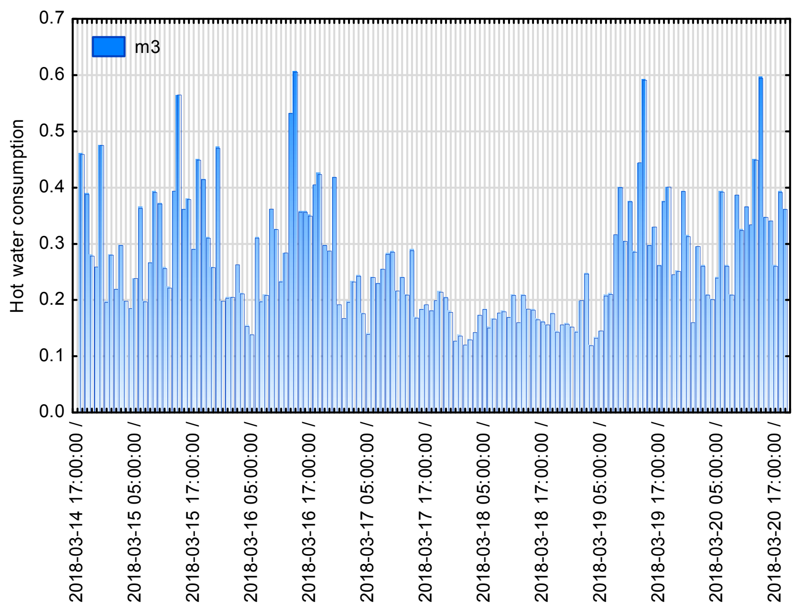

Fig. 1. Weekly hot water load pattern in the production hall.

Figure 2 shows hot water flow rates as measured over six days from Thursday to Tuesday and calculated flow rates according to selected formulae from Tables 1 and 2. The maximum measured value of flow rate was 0.623 l/s, while the average value from the period examined was 0.075 l/s. Most similar calculated values were obtained from the formula for schools and care homes determined according to DIN [19].

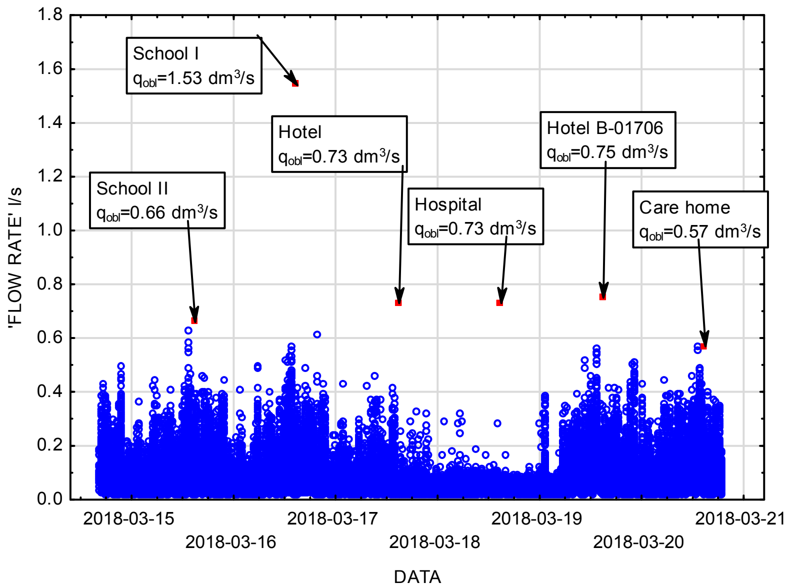

Fig. 2. Distribution of water flow rate during six days (School I acc. [17], school II acc. [19]).

The water supply system operating hydraulically for the halls where a different number of people work on particular shifts should be designed for the shift with the highest number of people. However, attention should be paid to water flow velocities during other periods as low velocities contribute to bacterial growth in the system [21]. Figure 3 illustrates water flow velocity in hot water system over six days from Thursday to Tuesday. Measurements were made on the cold water pipe at the inflow pipe to the DHW storage tank. It is a steel pipe measuring 48.6x2.8mm in diameter. According to the standard, the admissible velocities in a system amounts to 1 m/s in the distributing pipes and 1.5 m/s in the risers and branches. The diagram shows that water velocities are not higher than 0.45 m/s on weekdays and 0.1 m/s during the weekend when fewer people are at work. These velocities show that the system is oversized. The domestic hot water system downwards to the storage tank is made out of copper tubes where, for the reason of erosion-corrosion, the water flow velocity should not exceed 1 m/s in horizontal conduits and 2 m/s in connections [22, 23].

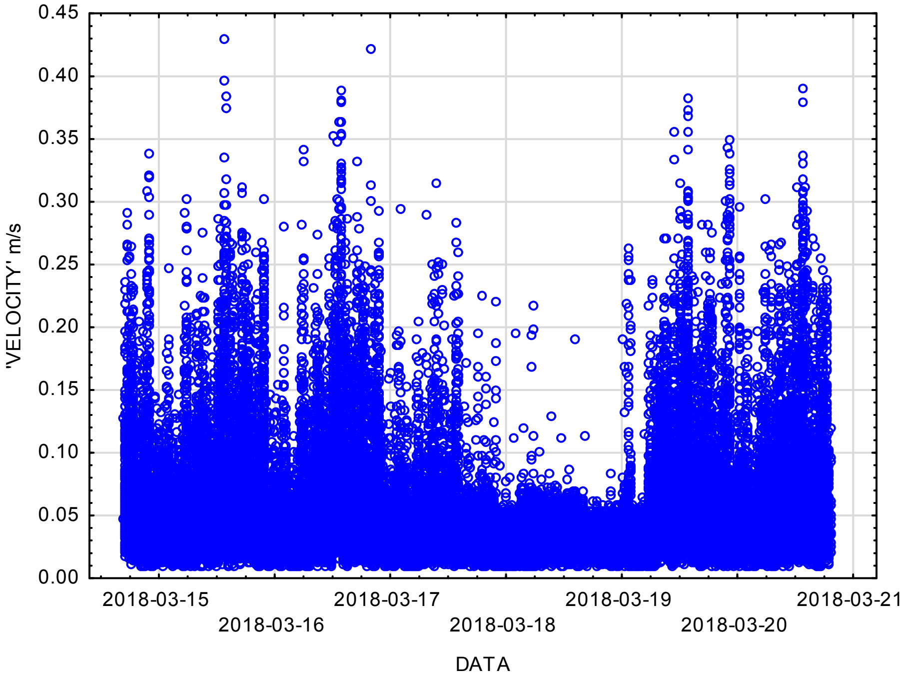

Fig. 3. Distribution of hot water velocity during six days.

4 Conclusion

The determination of design flow rate for the hall-type building is not straightforward. Various demands for different purposes and the dynamics of distribution and sanitary outfit of the hall need to be analyzed thoroughly to find the proper method of flow calculations. As it resulted from the comparison made for calculated water flows, these values differ from 170% for a small sum of rated outflows to 457% for a large sum of these outflows.
Measurement values from the period of examinations are, in most cases, lower than the values calculated with different methods. The value of one-second flow measurement is most similar to the flow determined from the formula for schools and care homes according to DIN [19].

The participation in the conference was co-financed by the Faculty of Environmental Engineering, Wroclaw University of Science and Technology, Poland (awarded by the Ministry of Science and Higher Education in the years 2017–2018 No. 0401/0007/17).

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