DHW design flow rates in educational, office buildings and shopping centers

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Abstract: - The paper gives a thorough survey of the studies of different authors in the field of domestic hot water (DHW) consumption. It presents an overview of the research done into DHW by Tallinn University of Technology. New empirical formulas for determining design flow rates for schools, kindergartens and office buildings have been worked out on the basis of investigations. Comparisons are given on the determination of DHW design flow rates by the standard EVS 835, EN 806-3 and the recommended formulas. The latter makes it possible to considerably decrease the design flow rates, which in turn enables to diminish the load of the equipment, improve the quality of control and decrease the diameters of the pipes of the district heating network and the losses of heat in them.

Key-Words: DHW, DHW design flow rate**,** schools, kindergartens, office buildings

1 Introduction

Extensive research into domestic hot water (DHW) consumption was done in the former Soviet Union in the 60s and 70s of the past century and even earlier. The results of the research have been presented by Hludov [28] and Brodski [29]. DHW consumption and consumption profiles in the 60s and 70s of the past century are presented in articles Borodkin et al. [1], Brodski [2], Kõiv [3]. The articles showed that the DHW consumption then was close to the standard figures given in the designing code.

Later DHW consumption and the consumption profiles have been treated in many countries.

In Asia mention can be made of a year-round study of DHW consumption in Hong-Kong's quality hotels, and investigations of DHW consumption and the load consumed for heating water by Deng et al [4]. An article by Cheng deals with studies of DHW consumption in Taiwan's residential buildings and with energy saving possibilities in water heating [5].

An article by Carrington, Warrington and Yak treats of DHW consumption in New Zealand's households [6].

In Africa investigations of DHW consumption have been carried out in the Republic of South Africa, in Senegal and in Egypt. In Johannesburg a year-round study of DHW consumption was carried out in which the researchers Meyer and Tshimanhinda also displayed the hourly consumptions [7]. Problems of DHW consumption are also dealt with in Vine's, Diamond' and Szydlowski's article [8] and Rankin's and Roussau's article [9], both in South Africa. In the articles by Meyer gives a survey of DHW consumption in South Africa also [10, 11]. Calmeyer and Delport have dealt with the subject of DHW consumption, including variations in consumption, in a student' hostel of Pretoria University [12].

In Senegal the influence of DHW parameters on energy consumption in public buildings and plants have been presented by Ndoye and Sarr [13].

In Egypt problems of heating DHW and saving energy have been investigated by Hegazy et al. [14].

In Brazil an investigation has been carried out by Prado and Gonçalves that deals with energy consumption for heating water in residential buildings [15].

In Hungary Nemethi and Szantho have studied DHW consumption and the consumption profiles in more than 60 residential buildings [16, 17].

An article by Rajala and Katko deals with domestic water consumption in Finnish households [18].

One of the few doctoral theses has been written by Savičkas in Lithuania [19]. The thesis comprises the DHW systems of apartment and public buildings, their functioning, DHW consumption, variations in the consumption and DHW temperature.

The year 1998 saw a thorough investigation of DHW consumption in English residential buildings [20]. Its main aim was to gather data on DHW consumption in residential buildings and the habits of their inhabitants. In the years 1991-1995 more than 10,000 residential buildings were investigated. A restudy comprising 2600 residential buildings was carried out in 1998.

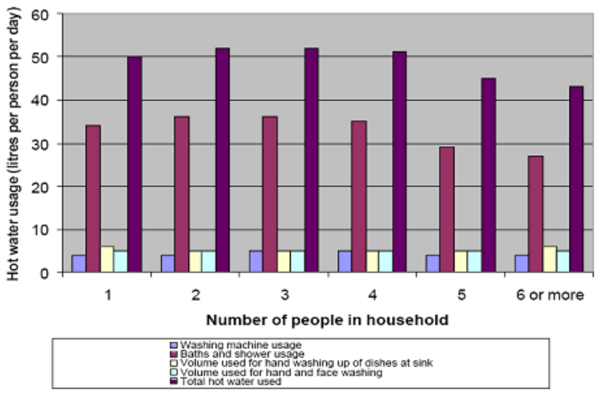

Fig. 0. Average DHW consumption depending on the number of inhabitants in the households

The aim of the study was to find out how DHW consumption varies from household to household and if there are any concrete types of households the DHW consumption of which is bigger than the average one. The study showed that the average DHW consumption by washing machines was 4 l/per person per day, by showers and baths 35 l/per person per day, and an additional 10 l/per person per day for hygiene and dishwashing in a sink. All in all DHW consumption was 49 l/per person per day. Concerning different types of households the results of the study showed that in households with younger inhabitants more DHW is used than in those with elderly inhabitants, Fig.1.

The largest number of investigations in the field of DHW consumption have been made in the U.S. The ones carried out more recently are mentioned. In 1995 ASHRAE issued new instructions for designing DHW systems in apartment buildings [21], their aim being the prevention of over dimensioning the systems. In reality the current DHW heating devices proved to be 30-200% over dimensioned practically all over America, because very big reserve coefficients were used. The research by Fairey and Parker [22] gives a survey of the DHW systems used in the United States. The investigation shows that depending on the consumption rate and the peculiarities of the DHW heating devices in single-family residences the consumption of energy necessary for heating water decreases 10-35% if water is heated by DHW instantaneous heat exchangers and not by tank heat exchangers. A study by Hendron and Burch [23] gives a survey of DHW consumption and the consumption profiles in households.

A number of investigations in the field of DHW have been carried out in Canada. An article by Aquilar, White and Ryan [24] points out that the share of DHW heating makes up 22% of energy consumption in Canadian households.

Several countries have drawn a lot of attention to the possible development of the pathogenic microorganism Legionella in DHW systems [25, 26, 27, 28]. The problem may turn out to be especially sharp in case the respective microorganisms exist in the initial water and the temperature of the water, for example, in the water heating devices remains on a relatively low level of 25 ... 45 ^{o}C

In Estonia, at Tallinn University of Technology (TUT) investigations concerning DHW consumption and the consumption variability have been made by Koiv , Toode and Lahe [29, 30, 31, 32, 33, 34].

An extensive DHW consumption investigation was carried out in Estonian apartment buildings in the years 1999…2011 (in 98 apartment buildings).

The extent of hot water consumption in different apartment buildings in the years 1999-2004 is presented in Fig. 2. As the results show, the average hot water consumption – 60 liters per day per person in 1999 – has decreased up to 44 liters per day per person in 2004.

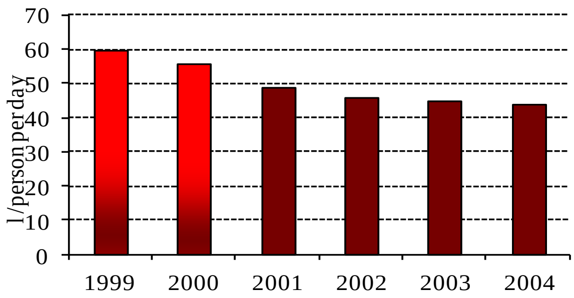

Fig. 2. Dynamics of average hot water consumption in the buildings analyzed

It can be seen that an increase in the percentage of water meters in apartments is accompanied by a considerable fall in water consumption. A decrease in water consumption has likewise been influenced by a rise in the price of both water and heat in recent years. A certain role in the decrease of water consumption has been played by the renovation of DHW systems. Of prime importance in it have been the renovation of DHW circulation and also the use of water, water saving equipment (lever mixers, showers).

In the diagram presented in Fig. 3 the comparison of weekly average DHW consumption within 30 years is of special interest. The results are presented in l/m² per day. Comparing the average DHW consumption per 1m² of heated area today and in the 70s, we can see that it has decreased 3.3 times. This fact also accounts for the relatively insignificant increase in variation in analogous residential buildings investigated.

Fig.4 Shows DHW consumption l/person per day in years 2005-2008 in Estonia

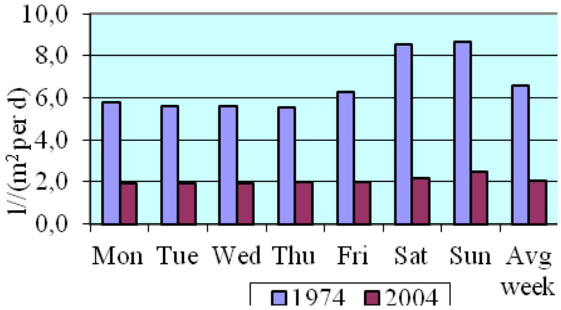

Fig. 3. Average DHW consumption per weekdays and per week in the years 1974-2004

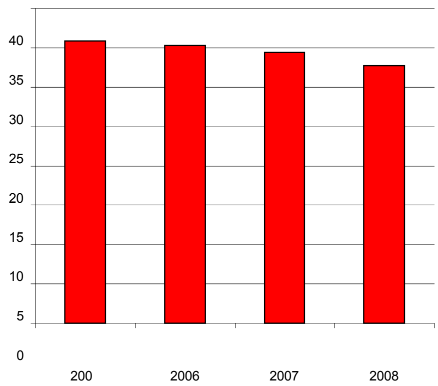

Fig.4. DHW consumption l/person per day in years 2005-2008 in Estonia

The DHW maximum consumption was investigated in 23 residential buildings of 18-, 30-, 35-,40-, 60-, 80-, 90-, 120-, 165-apartments. Impulse water meters with data loggers were used for measuring the maximum consumption of DHW. Maximum DHW flow rates (maximum values for the groups) in the apartment buildings investigated are presented in Table 1.

Below a formula is presented for determining the heating load of DHW instantaneous heat exchangers if the temperature difference of hot and cold water is 50°C.

$$\Phi_{sv} = 30 + 15 \cdot \sqrt{2 \cdot n} + 0.2 \cdot n \qquad (1)$$

where n is the number of apartments.

Fig. 4 presents the loads of DHW instantaneous heat exchangers determined for apartment buildings by the proposed formula (1), by Estonian standard EVS(D1) [35] and by the EN standard [36] against the background of the maximum values of the results of measuring.

Fig. 4 shows that in larger apartment buildings the heating loads of the heat exchangers differ up to two times in comparison with the EVS standard and up to 2.7 times in comparison with the EN standard.

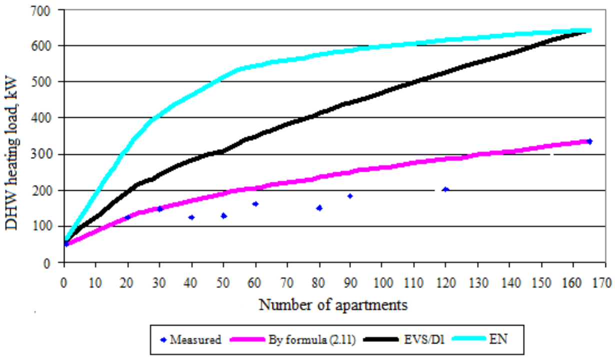

Fig. 4. DHW design heating load depending on the number of apartments by the EVS(D1) standard, the EN standard and the proposed formula together with the points calculated on the basis of the results of measuring

Table 1 Maximum DHW flow rates (maximum values for the groups) in the apartment buildings investigated

Number of apartments	Flow rate l/s
18	0.64
30	0.71
40	0.59
48	0.66
60	0.77
80	0.73
90	0.89
120	0.96
165	1.61

The analysis shows that in the conditions of the changed DHW consumption today the calculation methods valid untill now are not suitable and cause considerable over-dimensioning of the equipment and pipes and disorders in the functioning of DHW control units.

2 Method

An investigation of the maximum consumption of DHW has been carried out in 20 educational buildings, 16 kindergartens and 16 office buildings in Tallinn.

For studying the maximum consumption of DHW impulse water meters were used. For recording the data they were connected with data loggers. Data processing was made by the software PDL-Win. DHW consumption in the building with a precision of 1 l was recorded during a week.

The hourly variability in DHW consumption is indicated with the ratio of the given hourly consumption to average hourly consumption of a week k_h, which is calculated by the correlation:

$$k_h = \frac{G_{h,week}}{G_{h,week}^{average}}, \qquad (2)$$

where $G_{h,week}$ is the given hourly DHW consumption; $G_{h,week}^{average}$ is the average hourly DHW consumption of the week.

3 Maximum consumption of DHW and recommendations for determining the design flow rates for schools, kindergartens and office buildings

In Estonia it was customary to determine DHW design flow rates for schools, kindergartens and office buildings proceeding from the sum of the standard flow rates (the EVS method). It must be pointed out, however, that in a number of types of buildings (e.g. schools and office buildings) the use of a large number of DHW devices (first of all mixers) is very small, practically nonexistent. Such a situation leads to a considerable over-dimensioning of DHW heating devices and insufficient control of DHW temperature.

3.1 Schools and highschools

The design flow rates recorded in schools and those determined by the standard EVS 825:2003 [35], the European standard EN 806 – 3 [36] and the calculation of design flow rates by formula (3) are presented in Table 2.

Table 2 Comparison of the design flow rates determined by the results of recording with those determined by EVS 835: 2003, EN 806-3 and by formula (3) in school buildings

School/ Educa-tional Iinstitu-tion	Design flow rate by EVS 835 l/s	Design flow rate by EN 806 – 3 l/s	Recor-ded max-mum flow rate l/s	Design flow rate by calcu-lation for-mulas (3) l/s
S1	1.01	4.54	0.62	0.75
S2	0.85	3.66	0.3	0.74
S3	0..69	2.72	0.26	0.72
S4	1..31	5.2	0.71	1.05
S5	1.05	4.56	0.6	0.93
S6	0.83	3.99	0.25	0.65
S7	1.44	5.43	0.44	1.03
S8	0.75	3.46	0.6	0.78
S9	0..63	2.83	0.49	0.49
S10	1.29	5.19	0.77	0.82
S11	0.68	2.99	0.63	0.71
S12	0.94	3.95	1.06	1.10
S13	0.9	3.78	0.61	0.65
S14	1.38	5.35	0.64	1.17
S15	1.29	5.14	0.46	0.83
S16	0.62	2.22	0.47	0.53
S17	0.94	3.66	0.6	0.67
S18	0.6	2.65	0.54	0.63
S19	0.98	4.45	0.85	0.94
S20	0.98	4.16	0.36	0.50

A new empirical formula is recommended for determining the design flow rates (3) on the basis of which the water heating devices are selected for schools and higher educational institutions without swimming pools

$$q = 0.0035 \cdot N_1 + 0.00075 \cdot N_2 + 0.0009 \cdot N_3 \qquad (3)$$

where q is the design flow rate l/s; N_1 is the number of showers, N_2 is the number of students, N_3 is number of water outlet devices.

In Table 2 it can be seen that the design flow rates determined by the calculation formula (3) are approximately up to 2 times smaller than those calculated by the EVS standard and about 5 times smaller than those determined by the EN standard.

The big difference between the actual consumption of DHW and the consumption determined by the standards is due to the fact that the standards are based on the conditions that existed decades ago. Thus, according to the standards obtained the probability consumption does not meet the current situation. Fig.5 shows the comparison of design flow rates determined for schools by the empirical formula, the standard EVS 835 and the recorded values. It can be seen that in about 50% of the schools the design flow rates determined by the empirical formula (3) are considerably smaller, in about 30% of the schools they are somewhat smaller and in 20% of the schools they are equal or somewhat bigger compared with the standard EVS 835. At the same time the correlation with the actual design flow rates is better as with determining the design flow rates with formula (4) the number of water outlet devices is marginal as their use is episodic.

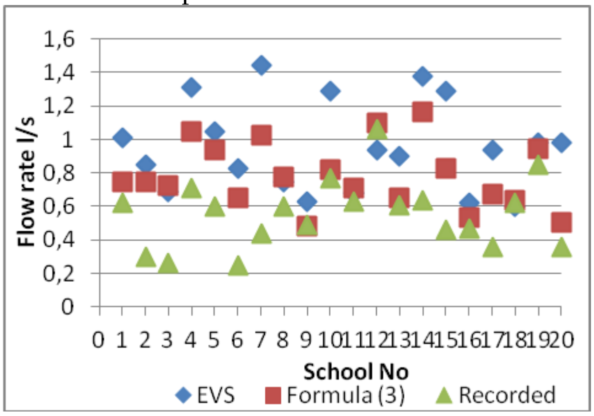

Fig.5. Comparison of the design flow rates determined for schools by the empirical formula (3), the standard EVS 835 and the recorded values

At a same time the association with the actual design flow rates is better as the calculation depended on the number of water outlet devices only slightly, the majority of which are used marginally.

3.2 Kindergartens

The design flow rates recorded in kindergartens and those determined by the standard EVS 825:2003, and the design flow rates calculated by formulas (4) are presented in Table 3.

Table 3 Comparison of the design flow rates determined by the results of the recording with those determined by EVS 835: 2003 and formula (4)

Kin-der-garten	Number of children	Design flow rate by EVS 835 l/s	Recorded maximum flow rate l/s	Design flow rate by calculation formula (4) l/s
K1	240	1.02	0.66	1.02
K2	86	0.55	0.17	0.34
K3	111	0.61	0.52	0.49
K4	179	0.94	0.43	0.78
K5	82	0.85	0.21	0.41
K6	215	1.09	0.57	0.96
K7	220	0.54	0.47	0.81
K8	160	0.70	0.42	0.64
K9	230	1.08	0.48	1.01
K10	210	1.09	0.79	0.94
K11	240	1.13	0.82	1.06
K12	240	1.21	0.86	1.09
K13	153	0.85	0.51	0.66
K14	100	0.70	0.39	0.43
K15	103	0.70	0.43	0.44
K16	94	0.60	0.39	0.39

In Table 3 we can see that the design flow rates determined by EVS 835: 2003 are bigger than the actual ones, which results in over-dimensioning the DHW instantaneous heat exchangers and the control devices.
As the design flow rates determined by the EVS standard are up to 1.8 times bigger than the measured ones in kindergartens, a new empirical formula is presented for determining them in selecting water heating devices (4)

$$q = 0.0009 \cdot N_1 + 0.0035 \cdot N_2 + 0.0025 \cdot N_3 \text{ l/s} \quad (4)$$

where N_1 is the number of showers, N_2 is the number of children, N_3 is the number of water outlet devices.

Table 3 shows that the design flow rates determined by formula (4) are up to 1.7 times smaller than the ones determined by the EVS standard.

3.3 Office buildings

Table 4 presents the design flow rates recorded in office buildings and those determined by EVS 835: 2003, EN 806-3 and building parameters. A comparison of these standards values with the results of the recording is given in Table 4.

A new empirical formula (5) for determining the design flow rates in dimensioning water heating devices was recommended

$$q = 0.0081 \cdot N_1 + 0.0019 \cdot N_2 + 0.0032 \cdot N_3 \quad (5)$$

where q – design flow rate l/s; N_1 − the number of showers; N_2 − the number of people; N_3 − the number of water outlet devises.

Table 4 shows that the use of EVS 835: 2003 leads to a most considerable over-dimensioning of the instantaneous heat exchangers and control devices of DHW. In Table 4 it can be seen that the design flow rates of office buildings determined by the Euro standard are not suitable for Estonia, because the results obtained are more than 10 times bigger than the measured consumption in office buildings. The reason is that the probability consumption does not meet the current situation.

Table 4 Comparison of the design flow rates determined by the results of the recording with those determined by EVS 835: 2003 and EN 806-3 in office buildings

Address	Number of people	Number of showers	Number of water outlets	Design flow rate by EVS 835 l/s	Design flow rate by EN 806-3 l/s	Recorded maximum flow rate l/s	Design flow rate by calculation formula (5) l/s
O1	152	6	41	0,8	3,3	0,26	0,47
O2	110	3	15	0,53	1,8	0,19	0,28
O3	160	6	36	0,75	3,1	0,38	0,47
O4	150	1	19	0,58	1,98	0,2	0,35
O5	104	2	17	0,55	1,9	0,24	0,27
O6	185	4	25	0,69	2,55	0,31	0,46
O7	240	5	42	0,85	3,3	0,56	0,56
O8	200	2	37	0,76	3	0,31	0,51
O9	125	7	35	0,74	3,12	0,2	0,41
O10	400	9	59	0,95	3,86	0,67	1.02
O11	95	1	19	0,56	1,98	0,14	0,25
O12	140	2	25	0,64	2,4	0,23	0,36
O13	240	3	29	0,65	2,7	0,45	0,57
O14	250	1	28	0,67	2,55	0,43	0,57
O15	175	4	44	0,79	3,32	0,36	0,51
O16	117	2	20	0,56	2,11	0,13	0,30

Table 4 shows that the design flow rates in office buildings determined by the standard EVS 835 are about 4 and even more times bigger than the maximum flow rates measured. The results obtained by determining the flow rates by the Euro standard are even up to 15 times bigger than the maximum flow rates measured. For that reason a new empirical formula has been worked out for determining the design flow rates for office and public buildings (5).

Table 4 shows that the design flow rates determined by formula (5) are up to 2 times smaller than those determined by the standard EVS and up to 8 times smaller than the design flow rates determined by the Euro standard.

Fig.6. presents a comparison of the design flow rates determined for office buildings by the empirical formula (5), the standard EVS 835 and the recorded values. We can see that design flow rates determined by the formula (5) are more close to recorded values.

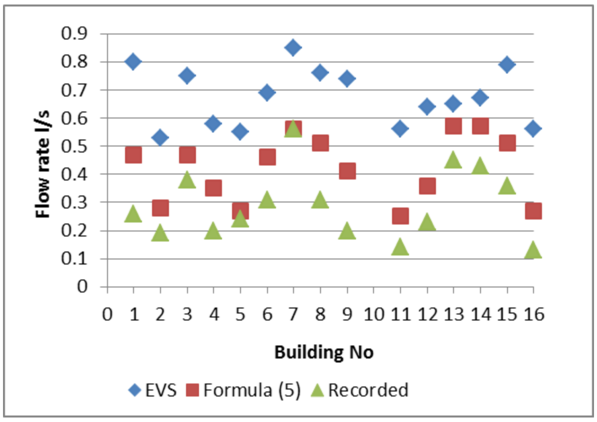

Fig.6. Comparison of the design flow rates determined for office buildings by the empirical formula (5), the standard EVS 835 and the recorded values

3.4 Shopping centers

Table 5 gives a comparison of the recorded maximum flow rates, design flow rates determined by the standard EVS 835 and the formula (6) and the values that affect the water consumption.

Table 5 shows that the DHW design flow rates determined for trade centers by the standard EVS 835 are at least 3 times bigger than the actual maximum consumption. Such a situation made it necessary to work out a new calculation formula for determining the DHW design flow rates for trade centers.

One of the reasons for the great difference between the actual DHW maximum consumption and the design flow rates determined by the standard EVS is the fact that the preparation of semi-fabricated food on the spot has been finished.

Table 5 Comparison of the recorded maximum flow rates, design flow rates determined by the standard EVS 835 and the formula (6)

Shop-ing center	Number of visitors per week	Num-ber of sho-wers	Num-ber of wa-ter out-lets	Design flow rate by EVS EVS 835 l/s	Recor-ded maxi-mum flow rate l/s	Design flow rate by calcu-lation formula (6) l/s
Rimi I	21000	20	66	1,25	0,27	0,30
Rimi II	32000	15	40	0,92	0,23	0,23
Rimi III	50000	6	46	0,89	0,27	0,27
Rimi IV	60000	2	26	0,68	0,18	0,22
Rimi V	85000	9	59	1,02	0,30	0,40
Selver I	19600	5	44	0,87	0,14	0,20
Selver II	27000	5	18	0,62	0,13	0,13

Below we present a new recommendable calculation formula (6)

$$q = 0{,}00185 \cdot N_1 + 0{,}0000022 \cdot N_2 + 0{,}0033 \cdot N_3 \quad (6)$$

where q is design flow rate l/s; N_1 is number of showers; N_2 is number of visitors; N_3 is number of water outlets.

4 Conclusion

In a situation where DHW consumption has drastically decreased a need arises for new calculation formulas for determining DHW design flow rates.

The DHW design flow rates determined for dwellings and office buildings by the recommended empirical formulas are about two times smaller than those determined by the method EVS 835.

In the papers of several investigators it has been pointed out that for heating DHW it would be suitable to use instantaneous heat exchangers instead of tank type water heaters. This would at the same time decrease the problems concerning Legionella.

Calculations show that if in determining the tree-figured DH networks we could use the recommended DHW design flow rates and in dimensioning the pipes of the DH networks consider the probable flow rates, the cost of building a DH network would decrease about 25% and the cost of maintenance (due to a decrease in heat losses) about 8 % [39].

5 Acknowledgements

The publication of this article was supported by the ESF measure 1.2.4 Development of cooperation and innovation of universities, the sub-measure "Doctoral Schools" that finances the project "Construction and Environmental Engineering PhD School"–project code 1.2.0401.09-0080.

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