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Peak Power of Heat Source for Domestic Hot Water Preparation (DHW) for Residential Estate in Poland as a Representative Case Study for the Climate of Central Europe

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Abstract: Due to the energy transformation in buildings, the proportions of energy consumption for heating, ventilation and domestic hot water preparation (DHW) have changed. The latter component can now play a significant role, not only in the context of the annual heat demand, but also in the context of selecting the peak power of the heat source. In this paper, the comparison of chosen methods for its calculation is presented. The results show that for contemporary residential buildings, the peak power for DHW preparation can achieve the same or higher value as the peak power for heating and ventilation. For this reason, nowadays the correct selection of the peak power of a heat source for DHW purposes becomes more important, especially if it uses renewable energy sources, because it affects its size and so the investment cost and economic efficiency. It is also indicated that in modern buildings, mainly accumulative systems with hot water storage tanks should be taken into account because they are less sensitive to design errors (wrongly selected peak value in the context of the uncertainty of hot water consumption) and because they result in acceptable value of peak power for DHW in comparison to heating and ventilation.

Keywords: domestic hot water; peak power; energy performance of buildings; DHW; energy transformation

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1. Introduction

The energy consumption in buildings is constantly changing, mainly due to the amendments of legal requirements. Examples of such activities are, for example, energy certification, CO_2 emission limits, local programs supporting the modernization of existing facilities, as well as subsidies for new, energy-efficient buildings and systems. Currently, a lot of emphasis is placed not only on reducing the energy demand itself, but also on increasing the degree of use of renewable energy sources (RES), which favors the reduction of primary energy consumption and reduces the depletion of fossil fuel resources. It can be seen that it is not possible to clearly state how much energy consumption should be reduced, because it depends on many parameters. For example, in the paper [1], the optimum energy usage for residential buildings in developing countries is discussed as vulnerable to the current economic situation in the given country. In the last few decades, much attention has been devoted to the analysis of thermal modernization of buildings and research on the energy efficiency of heating, ventilation and air conditioning systems (HVAC). For example, the article [2] presents the results of long-term research showing energy savings resulting from the use of thermostatic valves, ranging from 7% to 23% for the analyzed cases. The results of the research presented in the article [3] showed that the use of mechanical ventilation systems with heat recovery from the air removed in residential buildings allows for significant savings in the annual amount of energy, and at the same time confirmed that recuperator systems with an integrated wall intake-exhaust devices are safe to use from a hygienic point of view. In the paper [4], the review of the heat recovery methods in ventilation was presented as a way to diminish energy demand for heating the buildings. Another of the possibilities of reducing primary energy consumption by mechanical ventilation systems is the use of earth-to-air heat exchangers (EAHEs), which has been shown in many works, e.g., in a review article [5] or in more detailed works about supporting ventilation systems by means of ground heat exchangers, e.g., [6–8] or mechanical analysis about improving the efficiency of EAHEs, e.g., [9,10]. Building heating systems that use renewable energy sources, such as heat pumps, achieve the highest efficiency in cooperation with low-temperature heaters. In practice, surface heating systems are mainly used. The most common system is floor heating, but in works [11,12], the innovative ceiling heating and cooling panels have been presented, showing the increase in their efficiency thanks to the use of an appropriately corrugated surface. An important role for the energy efficiency of HVAC systems is also played by controlling their efficiency, which was described in the example of wall heating systems with heat pipes in the article [13]. Renewable energy sources that are most often used to meet the energy needs of buildings are the energy of the sun, wind, ground and the use of the so-called waste heat (heat recovery, i.e., from exhaust air in ventilation). The energy of the sun can be harvested by using solar collectors to prepare domestic hot water, such as in 227 houses in California (USA), the experiences of which are described in the paper [14], or those compared in terms of effectiveness in the article [15]. The collectors may be of the tubular type, such as those mentioned just now, or of the flat type, such as those reviewed in [16]. Another way to obtain energy from the sun is to use photovoltaic panels (PV panels) which are used to generate electricity and were reviewed, for example, in the paper [17]. Wind energy is used much less frequently in buildings, as electricity generation is usually carried out by large wind farms, such as offshore wind farms described in [18] or classic ones, the optimization techniques of which are described in [19]. Soil energy can be used, for example, to heat/cool the ventilation air with the aforementioned earth-to-air heat exchangers or by using ground-type heat pumps, such as those described in [20]. There are many more examples of modern systems that are aimed at decreasing the energy demand in building and increasing the efficiency of its usage. Some of them were mentioned to introduce the Reader to the background of the changes that buildings are currently undergoing in terms of energy efficiency and the structure of HVAC systems.

Due to the changes in building envelope and HVAC systems, described above, the relationship between various components of thermal balance of the buildings is constantly changing. In the article [21] one can find that in the last decades the share of energy demand for ventilation in the energy demand for ventilation and heat transfer from the building increased from about 20% to about 60%. Thanks to the better insulation of the building and using the mechanical ventilation systems with heat recovery from exhausted air and earth-to-air heat exchangers [22,23], the specific heat power for heating the building decreased from about 150 W/m^2 to about 20 W/m^2. The heat demand for heating the hot water has also changed in the last decades, mainly because of the decreasing water consumption related to individual accounting of consumption and increasing water and energy prices. The decreased hot water usage caused the higher water consumption irregularity which influences the heating peak power of the heat source. In the literature, one can find articles presenting the results of research on the possibility of increasing the efficiency of domestic hot water preparation systems, such as [24], as well as analyzing the possibility of their integration with renewable energy sources [25], usage of phase change materials in solar domestic hot water systems [26,27] or verifying the influence of technical parameters of the hot water preparation system on its effectiveness [28]. The sheer volume of hot water consumption by building residents is also a subject of analysis. In the article [29], based on the example of several single-family houses, it was shown that the values of hot water consumption taken in the calculation of the building's energy performance may differ from the real consumption by up to 39%. The differentiation of user preferences, as well as the duration and time of hot water consumption, make it impossible to accurately determine its instantaneous, maximum flowrate. In practice, only simplified methods are used, based on empirical experience from the operation of existing systems. For this reason, in paper [30], the authors presented a new approach of quantifying the flexibility potential of residential heat pumps in the context of stochastic character of domestic hot water usage, highlighting the probabilistic meaning of hot water consumption. In the literature on hot water systems, one can find many works that focus on increasing their energy efficiency or comfort of use. Article [31] describes a method to improve control of hot water temperature that can result in significant energy and water savings thanks to using advanced mixing valves. Investigations presented in [32] were focused on research on plate shower heat exchanger to reduce the domestic hot water energy demand. The results of the prototype tests showed the possibility of heat energy savings for a family house up to 300 kWh/year. However, the analysis did not refer to the multitude of calculation methods and the selection of the peak power of devices for DHW preparation. The impact of the use of nanoparticles in the solar fluid on the efficiency of the DHW preparation system was analyzed in [33]. The improvement in the efficiency of the system was not analyzed against the current changes in peak power for heating and ventilation of buildings. In [34], instantaneous heat exchanger with chemical-based disinfection was analyzed, which enables the reduction of hot water temperature in the DHW system, which resulted in a reduction in the circulation heat loss up to 66% for the analyzed multi-family building. The selection of the system power in the context of the amount of hot water demand was not the subject of research. Another way to reduce the energy consumption of a hot water system is to use shower heat exchangers for heat recovery in residential buildings. The possibility of using such a system was presented, for example, in articles [35,36]. Energy savings in DHW systems can also be achieved by appropriate control of their operation, which was demonstrated in the work [37], which focuses on the analysis of the heat storage tank. The improvement of the energy efficiency of the DHW solar system due to the mechanical modification of the heat storage tank structure was the subject of the research presented in [38]. On the other hand, Chandra & Matuska [39] analyzed the quality of temperature stratification in heat storage tanks in the context of the energy efficiency of the DHW system. Heat storage tanks in DHW systems can also take advantage of the phase change phenomenon, if they are filled with PCM materials, as shown, for example, in the papers [40–42]. In turn, the paper [43] presents the importance of the storage tank (cold water inlets and obstacles) structure itself for the energy efficiency of the DHW preparation system, which, if appropriate, may result in up to 15% higher efficiency compared to the non-optimized structure. Optimization of the storage tank structure may also contribute to shortening, by up to 10%, the time of preparing hot water, which improves the comfort of its use and has been analyzed in [44]. In all of these studies on heat storage tanks, the impact of their use on the peak power of the heat source in the context of the available computational methods was not analyzed. The subject of the stochastic nature of the variability of hot water consumption by users was discussed in many articles. In the work [45], neural networks were used to predict the demand for hot water both in single houses and in multi-family buildings. In the analysis presented in the article [46], the DHWcalc and TRNSYS software was used to determine district heating load profiles for domestic hot water preparation. Probabilistic model for predicting occupancy and domestic hot water use was also presented in [47]. In the paper [48], the smart-meter was used to measure the instantaneous consumption of hot water, and the results of the analysis provided in the paper showed that “statistical and machine learning analysis can forecast the seasonal DHW demand”. Nevertheless, the tools used in the above-mentioned works go beyond the workshop of typical engineers, as well as scientists who deal with the subject of improving the energy efficiency of DHW systems by improving control systems or changing the design of system components. For this reason, this paper focuses on the comparison of generally available and popular methods of calculating peak power for DHW preparation purposes. The work [49], as well as [50], deal with the topic of life cycle costs in the context of hot water preparation systems. Important issues of the use of materials from their acquisition through the production and utilization process were emphasized; however, it was not analyzed in the context of various methods of selecting the peak power of heat sources and/or DHW system components. An interesting idea for increasing energy efficiency is the combination of an air-conditioning system and hot water preparation, which was presented, for example, in the works [51,52]. Thanks to this solution, waste heat from the cooling process of rooms, especially in warm climates, can be used to prepare hot water for household needs.

Due to the changes in the HVAC systems mentioned above, the current view on the selection of heat source peak power in the context of hot water preparation should be revised. In the review paper [53] on sustainable and energy-efficient domestic hot water systems, many publications and studies have been analyzed. Among them, the analyses that concern the determination of the peak power of a heat source for the purposes of preparing domestic hot water in the context of mentioned above changes in the consumption ratio were not found. In this paper, it is considered as a knowledge gap, and at the same time, an important issue to study from a practical point of view. In this article, this problem is discussed in the context of various methods of determining the peak power of a heat source for the purposes of preparing domestic hot water. Contrary to the work presented in the article [29], the focus is given on the power of the heat source, not on the energy consumed in the annual cycle of its operation. The changes that have taken place in buildings in terms of improving the thermal insulation of partitions and improving the efficiency of HVAC systems, in particular the use of heat recovery from the exhaust air in mechanical ventilation systems, have changed the ratio between the peak thermal power needed to prepare domestic hot water and the power for heating and ventilation. This means the need to revise the calculation methods used so far. The above literature review on DHW systems shows that this issue has not been analyzed. DHW systems are usually analyzed in terms of the possibility of using renewable energy sources or in terms of their efficiency, but little attention is paid to the peak power selection which affects the size, cost, heat loss, efficiency and the very possibility of cooperation with RES. Improper assumption of peak power (usually oversizing) will not allow to achieve the required savings and reduce the effectiveness of even the most theoretically effective solution. On the other hand, undersized systems will not provide users with a sufficient level of comfort.

2. Materials and Methods

2.1. Calculating the Heating Power for Preparing Hot Water

The universal formula for calculating the heating power for preparing domestic hot water can be given as:

$$\dot{Q} = \rho_{\mathrm{w}} \cdot \dot{V}_{\mathrm{hw}} \cdot c_{\mathrm{w}} \cdot (t_{\mathrm{hw}} - t_{\mathrm{w}})\ [\mathrm{kW}] \quad (1)$$

where:

ρ_{w}—density of water, [kg/m^3];
$\dot{V}_{\mathrm{hw}}$—volumetric flowrate of hot water, [m^3/s];
c_{w}—specific heat of water, [kJ/(kg·K)];
t_{hw}—temperature of hot water, usually assumed as 55 °C to avoid diseases connected with bacteria Legionella;
t_{w}—temperature of cold water, usually assumed as 5 °C for surface water sources and 10 °C for deep ground water sources.

In Equation (1), the assumption of the stream of hot water $\dot{V}_{\mathrm{hw}}$ (hot water consumption) is crucial.

2.2. Hot Water Consumption—Standard Method

The instantaneous amount of hot water consumption depends on the behavior of users, which cannot be predicted. Older people and people with small children, people who work at home and people who work shifts, etc., use water in different amounts and at different times. In existing buildings, you can measure the current water consumption with a water meter. This information is not sufficient to predict water consumption in newly built facilities whose users are unknown. Moreover, depending on the users (whether the same people still occupy the buildings) and on time (whether the users age, change jobs, habits, etc.), the measured value will change. Therefore, it cannot be defined once or unequivocally. For this reason, some simplifications and assumptions as well as various calculation methods are used in practice. Interestingly, they can result in values that differ significantly from each other, as demonstrated later in this work. The literature review shows that the hot water usage is difficult to predict due to unpredictable user behavior. Hot water consumption can be predicted on the basis of many statistical data from already existing buildings, inhabited by people with a similar consumption profile. For this purpose, probabilistic methods or neural networks are used, as indicated by the authors of the studies presented in the works, respectively, [46,47]. Due to the important role of the method of use for temporary water abstraction, the authors of the studies [48] write clearly not about its calculation, but "prediction", emphasizing the stochastic nature of this consumption, depending on the way the system is used by users. The authors of the review [54] also emphasize a significant impact on energy consumption in buildings, which, although it concerns heating, ventilation and lighting systems, seems to indicate a similar unpredictability of their use, as in the case of DHW systems. The authors of the model for optimizing energy consumption in a building [55], based on user behavior survey, also refer to "prediction" rather than "calculating" the actual values of energy consumption in a building.

Figure 1 shows the example of variability of hot water consumption in the case of a multi-family housing estate for three selected days of the week (Sunday, Thursday, Saturday) at different hours of the day. The chart is taken from a handbook on district heating [56].

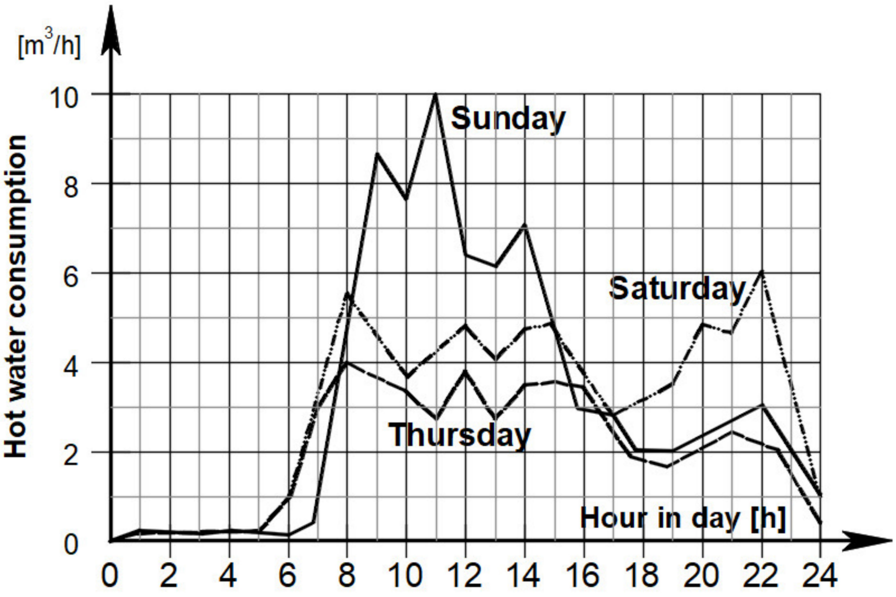

Figure 1. An example of hot water consumption for exemplary residential estate [56].

Due to the high variability of hot water consumption during the day, as well as week, month or year, the method described in the standard PN-B/92-01706 can be used. It allows us to determine the temporary hot water consumption assuming the average daily water consumption per capita and the number of inhabitants. The average daily consumption of hot water is a value that is also subject to fluctuations, not only depending on the users, but also in the long term, e.g., with a change in water and energy prices, a change in the wealth of a given community, or a change in the level of hygiene awareness. Nevertheless, it is a value that is easier to verify, e.g., on the basis of data from water companies. In this method, the daily consumption expressed in dm^3/person/day is then divided by the time of consumption during the day and multiplied by the coefficient of hourly consumption irregularity k_{h1}, which is an increasing factor aimed at calculating the peak (maximum) value of hourly water consumption:

$$\dot{V}_{\mathrm{hw,max}} = \frac{\dot{V}_{\mathrm{hw,av}} \cdot M}{\tau} \cdot k_{\mathrm{h1}} \tag{2}$$

$$k_{\mathrm{h1}} = 9.32 \cdot M^{-0.244} \tag{3}$$

where:

$\dot{V}_{\mathrm{hw,max}}$—peak (maximum) hourly hot water consumption, [dm^3/s];
$\dot{V}_{\mathrm{hw,av}}$—average daily hot water consumption per person, [$\mathrm{dm}^3/\mathrm{person/day}$];
M—the number of residents, [$-$];
τ—time of hot water consumption during the day, assumed usually as 18–20 h = 64,800–72,000 s, taking into account the time for sleeping;
k_{h1}—coefficient of hourly consumption irregularity, [$-$].

The coefficient k_{h1} decreases with the increase in the number of inhabitants, which reflects the assumption that the more people live in the housing estate, the greater the uniformity of heat consumption, i.e., the less probable a situation is that many people will take a shower or turn on the faucet in the sink at the same time. This assumption means that in the case of a small group of people, the risk of simultaneous consumption, significantly increased compared to the average value, is greater. This approach seems to be justified also due to the greater accumulation and hence the inertia of large domestic hot water preparation systems designed to serve a larger number of inhabitants.

In the standard PN-B/92-01706 the hot water consumption at the level of 110–130 $\mathrm{dm}^3/\mathrm{person/day}$ was recommended. Due to the water consumption changes (decreased hot water consumption to a level of about 60 $\mathrm{dm}^3/\mathrm{person/day}$) in 2011, in articles [57,58], it was recommended to assume adjusted value of the lower water stream and the higher irregularity of the consumption:

$$k_{\mathrm{h2}} = 8.8 \cdot M^{-0.167} \tag{4}$$

It should be noted that further changes in domestic hot water consumption will affect the value of peak consumption and the irregularity coefficient will increase. A survey presented in the paper [59] showed that "*the perspective of environmental protection is not a sufficient motivator to save energy for heating domestic hot water*" and therefore only the water and energy price model can drive further changes.

2.3. Hot Water Consumption—Experimental Measurements

The second method, taken into account in this study, is calculating the hot water consumption with approximated formulas based on the experimental data published in a book about hot water preparation systems [60] in 2008. Approximated results enable calculation of average and maximum hot water consumption as a function of the number of residents with the assumption of probability that this value would be exceeded (Equations (5)–(8)). For example, the probability of 1% means that the water stream can be exceeded once in one day for 100 days.

$$\dot{V}_{\mathrm{hw,av,1\%}} = 0.006386 \cdot M^{0.5} + 0.00102M\ [\mathrm{dm}^3/\mathrm{s}] \tag{5}$$

$$\dot{V}_{\mathrm{hw,av,10\%}} = 0.003048 \cdot M^{0.5} + 0.00102M\ [\mathrm{dm}^3/\mathrm{s}] \tag{6}$$

$$\dot{V}_{\mathrm{hw,max,1\%}} = 0.03017 \cdot M^{0.5} + 0.00102M\ [\mathrm{dm}^3/\mathrm{s}] \tag{7}$$

$$\dot{V}_{\mathrm{hw,max,10\%}} = 0.01429 \cdot M^{0.5} + 0.00102M\ [\mathrm{dm}^3/\mathrm{s}] \tag{8}$$

Due to the fact that hot water consumption is random, the use of probability for a mathematical description of this process seems to be the most reliable method. Moreover, this method allows us to select the comfort level understood as the probability of failure to maintain the continuity of hot water supply within the set parameters (stream and temperature). In this way, in the process of designing the system, it is possible to decide on its size, taking into account the compromise between the comfort (higher consumption values taken for calculations) and the cost of obtaining it (higher cost of purchasing and operating an oversized system), adjusting the solution to the expectations and financial possibilities of users. In this way, one can consciously design a larger system for a five-star hotel and a smaller one for a lower-standard hotel. However, it should be borne in mind that the presented formulas are the result of the approximation of measurement data of housing estates located in a one single city—Szczecin, Poland, Central Europe—for a limited set of buildings and only in the time period covered by the research. This means that the data used for calculations may not be inadequate for other settlements located in other cities or at a different time. It is a specificity related to the estimation of hot water consumption. Consequently, continuous monitoring of hot water consumption should be the subject of research. Recently, there have been published papers that show the changes that have occurred in this area during the COVID-19 pandemic, e.g., [61].

2.4. Hot Water Consumption—Sander's Method

Another method for calculation of hot water consumption, taken into account in this study, is the Sander's method described for example in the book [56]. In this method, the water stream for heating source peak power calculation is assumed on the basis of the hot water volume flowing from the water device, temperature of water and time of use:

$$\dot{V}_{\mathrm{hw}} = \frac{\sum N_{\mathrm{i}} \cdot V_{\mathrm{i}}}{\tau \cdot 60} \cdot \varphi \ [\mathrm{dm}^3/\mathrm{s}] \tag{9}$$

where:

N_{i}—number of each type of devices, [−];
V_{i}—the volume of hot water used during single use, [dm^3];
τ—time of single use, [min];
φ—coefficient of non-simultaneous consumption of hot water, [−].

Input values for calculating different water devices are presented in Table 1. The value of the coefficient of non-simultaneous consumption of hot water φ can be read from Figure 2. The coefficient is used to take into account that not all water devices will be used at the same time. This is especially important in the case of housing estates, where the greater value of peak power should be taken for the selection of heat exchangers (e.g., housing heat exchangers), and smaller for the selection of the central heat source (taking into account the non-simultaneous consumption, reading the coefficient for the total number of water devices supplied by the heat source at the whole estate).

Table 1. Typical values of volume flowing from the water device, temperature of water and time of use for calculating the peak power for hot water preparation using Sander's method.

Device	V **[dm^3]**	t_{hw} **[°C]**	τ **[min]**
Sink	10–15	35–40	2–3
Kitchen sink	30–50	55	5
Bath	150–250	40	15–20
Shower	50	40	6

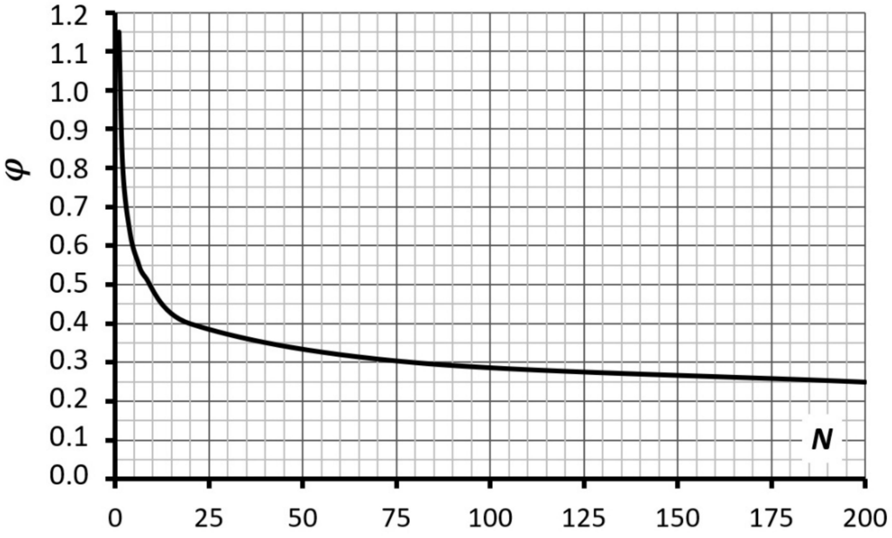

Figure 2. Value of coefficient of non-simultaneous consumption of hot water [56].

In practice for multi-family buildings, it is assumed that only the biggest water device should be taken into account as a representative for each flat. This approach assumes that a temporary and small consumption of hot water from other devices, such as a sink, will not result in a lack of power in the local hot water preparation system, which has a large thermal inertia. Then Equation (9) takes a simplified form, where only the number of baths or showers is taken into account:

$$\dot{V}_{\mathrm{hw}} = \frac{N_{\mathrm{bath/shower}} \cdot V_{\mathrm{bath/shower}}}{\tau \cdot 60} \cdot \varphi \ [\mathrm{dm}^3/\mathrm{s}] \tag{10}$$

For the bath, it can be assumed that the V_{bath} = 150–200 dm^3 of water at the temperature of 40 °C (100–133 of water at the temperature of 55 °C) is used in a time τ = 15 min. For showers V = 50 dm^3 at the temperature of 40 °C (35 dm^3 at the temperature of 55 °C) in a time of 6 min. In this method, one can easily take into account the presence of hot water storage tanks by setting a longer water preparation time τ, i.e., 60 min. It is possible to discuss the value of the hot water temperature that should be used in the calculations. The results of studies of two single-family houses in Denmark [62] showed that the temperature of the water used in the shower was 35.5 °C to 40.4 °C, and for hand washing 20.5 °C to 26.5 °C. Taking the bath as a representative device and assuming the hot water temperature of 40 °C seems to be justified in the context of the quoted research results.

To calculate the peak power, universal formula (Equation (1)) can be used, but it has to be noted that for different water devices, different values of hot water temperature should be taken into account (see Table 1).

3. Results

3.1. Comparison of Hot Water Consumption

All above-mentioned formulas result in different values of hot water stream. The differences in results are very high, as is shown in Figures 3–5. The assumptions for calculations with Equation (1) are as follows:

- The number of residents per one flat: M/N = 3.5;
- PN-B/92, av.: $V_{\mathrm{hw,av}}$ = 120 dm^3/person/day;
- PN-B/92, max.: $V_{\mathrm{hw,av}}$ = 120 dm^3/person/day, k_{h} calculated from Equation (2);
- PN modified 2011, av.: $V_{\mathrm{hw,av}}$ = 60 dm^3/person/day;
- PN modified 2011, max.: $V_{\mathrm{hw,av}}$ = 60 dm^3/person/day, k_{h} calculated from Equation (3);
- PN-B/92 and PN modified: time of hot water consumption during the day: 18 h;
- Sander, bath, flow-type: V = 100 dm^3, τ = 15 min;

- Sander, bath, accumulative: $V = 100\ \mathrm{dm}^3$, $\tau = 60$ min;
- Sander, shower, flow-type: $V = 35\ \mathrm{dm}^3$, $\tau = 15$ min;
- Sander, shower, accumulative: $V = 35\ \mathrm{dm}^3$, $\tau = 60$ min.

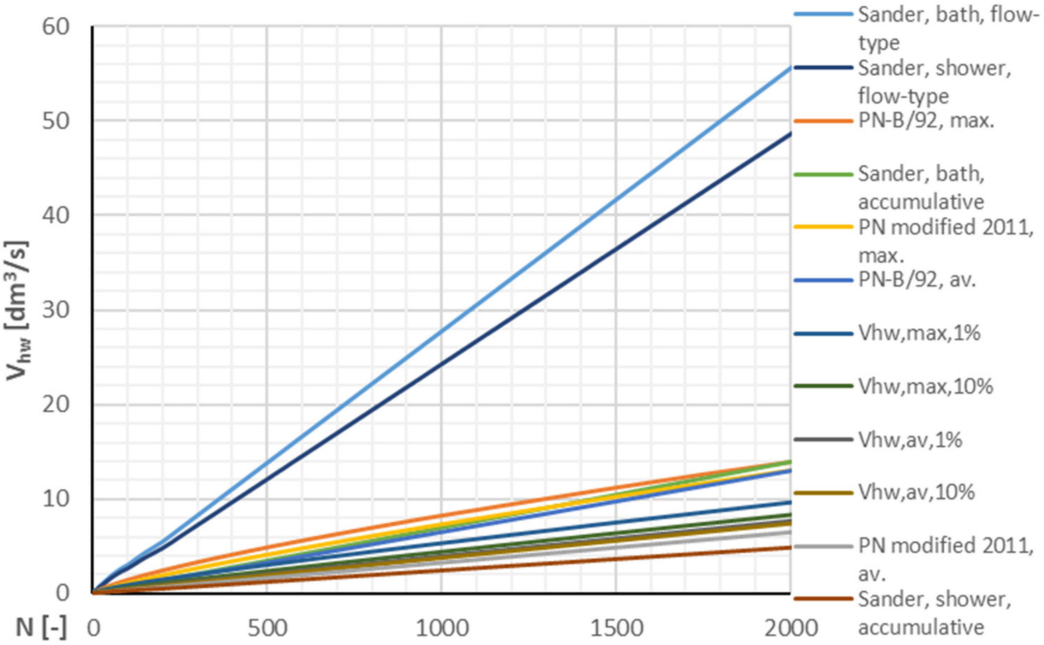

Figure 3. Comparison of hot water consumption calculated with different formulas, the number of flats: N = 0–2000.

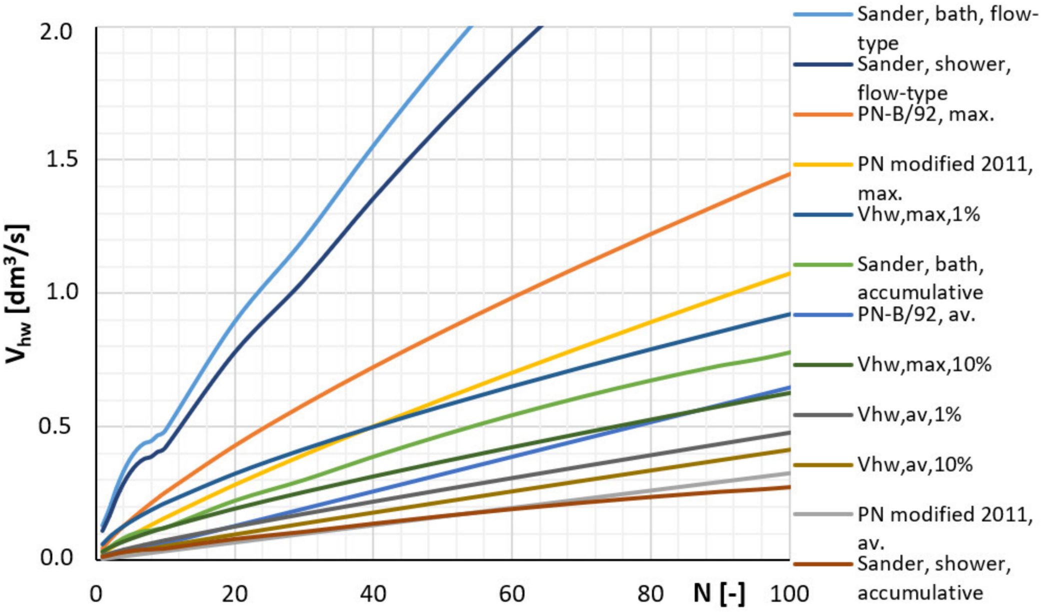

Figure 4. Comparison of hot water consumption calculated with different formulas the number of flats: N = 1–100.

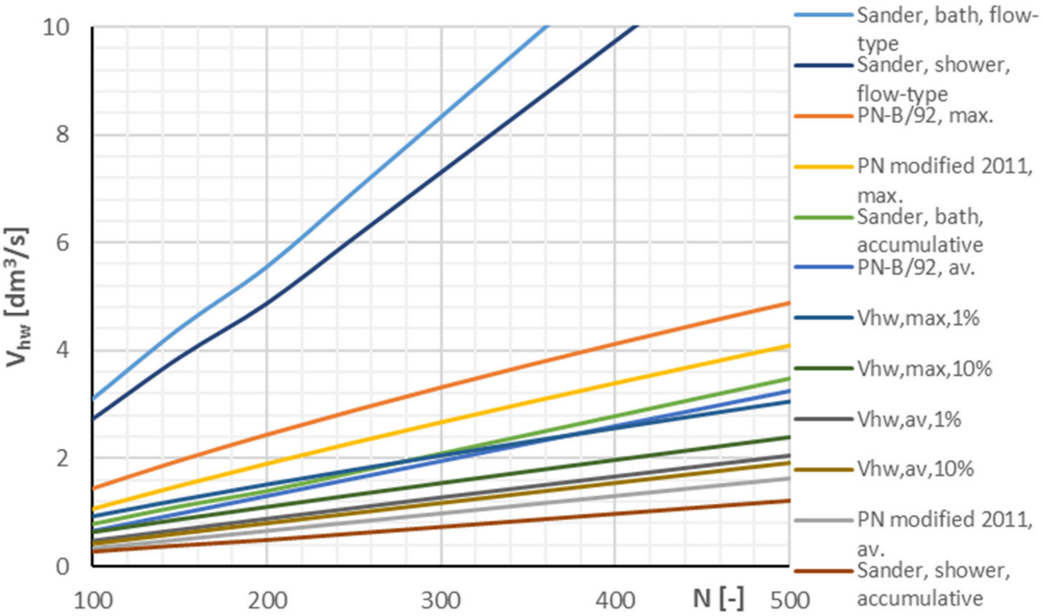

Figure 5. Comparison of hot water consumption calculated with different formulas, the number of flats: $N = 100–500$.

Results presented in Figures 3–5 show that:

- The highest value of hot water stream is obtained with Sander's method for flow-type system (without accumulation tanks), assuming baths as representative water devices;
- The lowest value of hot water stream is obtained with Sander's method for accumulative-type system (with accumulation tanks), assuming showers as representative water devices;
- Similar value as for Sander's method with accumulation tanks assuming showers was obtained using standard PN-B/92-01706 method and average (not maximum) stream of water (without taking into account coefficient k_h); for the number of residents 0 to 50 the Sander's method results in higher values and for $N > 50$ lower values (about 33%).

3.2. *Peak Power of the Heat Source*

For calculation of the heat source power for housing estate the power demand for heating the buildings and for hot water preparation should be taken into account. For buildings with high thermal inertia, the priority of hot water preparation can be assumed to reduce the peak power of the heat source. For traditional buildings with a high demand for thermal power for heating, the peak power could be calculated as a sum of heating needs and average hot water needs, but in the contemporary low energy buildings, this approach fails because of low heating needs. In Figure 4, the comparison of heat demand for heating the buildings in different insulation standards is presented. The results were prepared with assumptions:

- $Q_{hw,av}$ calculated from PN-B/92-01706, $V_{hw} = 60$ dm^3/person/day;
- $Q_{hw,max}$ calculated from PN-B/92-01706, $V_{hw} = 60$ dm^3/person/day, k_h calculated from Equation (3);
- Q_{co} calculated with assumption: $q_{co1} = 100$ W/m^2, $q_{co2} = 50$ W/m^2, $q_{co3} = 20$ W/m^2;
- The number of residents per one flat $M/N = 3.5$;
- The average area of a single flat: $A = 55$ m^2.

In Figure 6, the heating power for preparing hot water calculated from the Sander's method (for shower, flow-type and accumulative) and $V_{hw,max,1\%}$ are also presented.

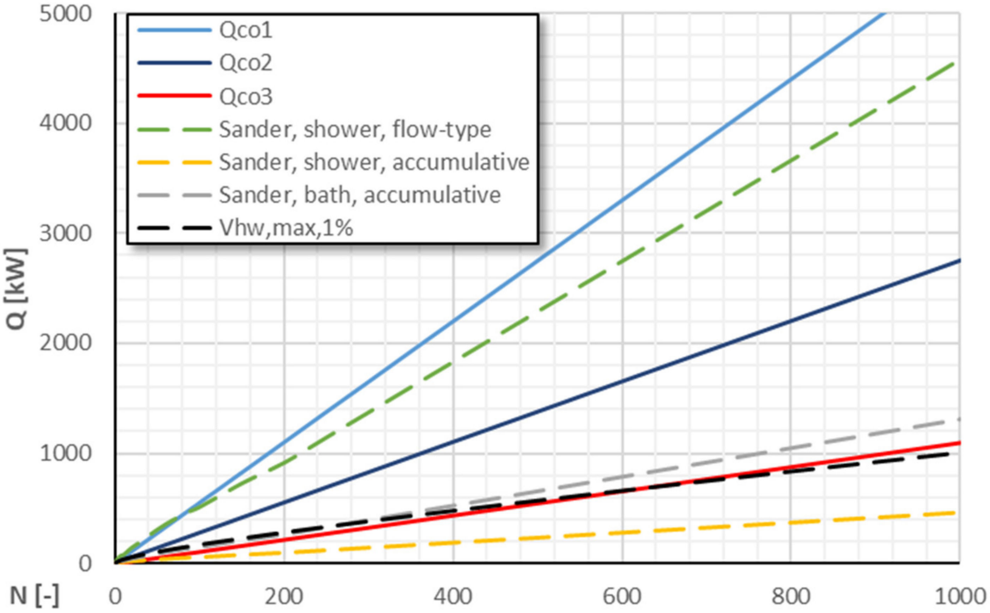

Figure 6. Heat source peak power for heating the buildings in different insulation standards and for preparing the hot water—comparison for *N* residents.

4. Discussion

The introduction to the work presents information on the energy transformation of buildings towards low-energy buildings. In the future, it will lead to the construction of nearly zero energy buildings (nZEB) or even plus energy buildings—as indicated by the case study showing the methodology of designing such facilities [63]. The results of this analysis showed that with the reduction of the thermal power for heating and ventilation purposes, the proportions between the peak power for these purposes and the power necessary for the preparation of domestic hot water changed significantly, as shown in Figure 6. It can therefore be seen that for low-energy multi-family buildings, the priority of hot water can be not sufficient for heating up hot water, especially when the baths are used instead of showers. For such buildings, the storage tanks are recommended to diminish the heat source peak power. In the context of diminished energy demand for heating and ventilation of the building, the priority of domestic hot water cannot be assumed without checking the peak power for hot water preparation. For the energy efficient buildings, the peak power for heating water can be the same or even higher than the peak power for heating and ventilation purposes. This indicates the need for changes in the approach to designing the peak power of a heat source in countries with a climate such as in Central Europe, where so far in traditional construction, the demand for heating and ventilation purposes was dominant.

In this study, the following methods of calculating the peak power for domestic hot water preparation were analyzed:

(1) PN-B/92-01706;
(2) Experimental results;
(3) Sander's method (flow-type and accumulative).

Each of the methods can be calibrated by changing the input data. In the case of the method based on experimental results, there is a possibility to choose a formula with a different probability of exceeding the peak consumption of hot water.

Method (1) PN-B/92-01706 is outdated and is based on non-updated values of daily hot water demand and uses an unverified coefficient of unevenness of hot water usage. Correcting—making real—the value of daily consumption does not guarantee obtaining reliable results. The method should be updated and validated against experimental data, taking into account the large number of objects analyzed. An interesting concept would be to make the results dependent on the chosen usage profile, which would be in line with the contemporary occupant-oriented designing trend.

Method (2) is based on the experimental data from the past that was averaged from measurements for a few selected buildings in a single city. For this reason, it is difficult to consider them universal. The advantage of this approach is to obtain the result of the peak hot water stream with information about the probability of the frequency of its exceeding (1% or 10%). Thus, this method enables the user to choose the degree of comfort of receiving hot water, and thus adjust it to the standard of the facility or the wealth of the users' wallet.

Method (3) Sander's method is based on the basic equations from the theory of heat flow. Therefore, it is the easiest to interpret physically, and it is also the easiest to verify the correctness of the entered data, because it is based on data on the amount of water flowing out at a given time from a given equipment. This method makes it possible to assume the hot water temperature depending on the regarded water device and to perform calculations for flow-type or accumulative systems. The only uncertain element of this method is the assumption of the simultaneous consumption factor, which depends on the number of water devices in a given building/estate. It is a data that can be read from a table or graph and cannot be confirmed personally. Nevertheless, according to the author, this method seems to inspire the greatest confidence, and in the case of the use of accumulation systems, results in peak heat power that is acceptable for modern buildings with low heat demand for other purposes (heating and ventilation).

5. Conclusions

Results of the work presented above show that:

- Different methods of calculating hot water consumption result in very divergent results;
- For the number of flats $n = 1$ to 100, the lowest values of hot water consumption are obtained with sander's method (shower, accumulative) and PN-B/92 (average stream, modified in 2011);
- The hot water consumption in the real buildings with the probability of exceed 1% $v_{\mathrm{hw,max,1\%}}$ (recommended in book [58]) is almost two times higher than the lowest ones;
- The average value calculated from PN-B/92 for 1–80 flats is lower than $v_{\mathrm{hw,max,10\%}}$ and for $n > 80$ is higher;
- For $n = 1$–80, $v_{\mathrm{hw,max,1\%}}$ is the most similar to the maximum water stream calculated from pn-b/92 modified in 2011;
- For $n = 100$–500, $v_{\mathrm{hw,max,1\%}}$ is the most similar to sander's (bath, accumulative);
- The maximum water stream calculated from PN-B/92 modified in 2011 for $n = 100$–500 is about 16–34% higher than $v_{\mathrm{hw,max,1\%}}$;
- The peak power for heating the hot water in the flow-type system can be a few times higher than the peak power needed for heating and ventilation purposes of the contemporary low-energy building.

The present study shows that a thorough analysis of the domestic hot water system is now necessary, as this element may be decisive in the selection of the peak power of the heat source. This is particularly important when using renewable energy sources (RES), when the cost of purchasing oversized units can frustrate investment and discourage RES use. The results of this study show that the reduction of source peak power should then be achieved by using accumulation systems with hot water tanks, which results in an acceptable peak power for DHW preparation in comparison with the power needed for heating and ventilation.

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