



## Article

# Real Domestic Hot Water Consumption in Residential Buildings and Its Impact on Buildings' Energy Performance—Case Study in Poland

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**Abstract:** A building's energy consumption is assessed considering the energy required for heating, cooling, lighting, and domestic hot water (DHW). Methodologies used to calculate energy certificates in European Union countries consider hot water consumption rates per person or per heated (floor) area, giving wide-ranging values (35–88 dm<sup>3</sup>/person/day). Using extreme parameters, it is possible to obtain a primary energy index that meets the legal requirements, although unrealistically large proportions of domestic hot water use relative to the total energy balance of the building may marginalize the influence of other components, such as fluctuations in heating, ventilation, or lighting. In the current work, the DHW consumption of three residential buildings was measured to verify the energy consumption for hot water preparation. Investigations were conducted based on the consumption of natural gas for DHW preparation. Experimentally obtained water consumption rates were determined per m<sup>2</sup> of a dwelling and per person living in the building. The calculated indicators (0.85 ± 0.005 dm<sup>3</sup>/m<sup>2</sup>/day and 27.4 ± 1.4 dm<sup>3</sup>/person/day) were lower than those used for energy certifications of buildings. The experimentally obtained indicators were used in further theoretical energy assessments of six residential buildings. By adopting the designated indicators, the analyzed buildings met the legally required primary energy value (<70 kWh/m<sup>2</sup>/year) when using natural gas as a heat source. Applying more realistic DHW consumption values resulted in more accurate energy certifications.

**Keywords:** domestic hot water consumption; energy performance of buildings; domestic hot water; energy certification; water resources



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## 1. Introduction

Globally, lowering energy consumption in buildings helps to reduce greenhouse gas emissions, reduce fossil fuel extraction and reduce the environmental costs of transporting them. Buildings are responsible for around 40% of energy consumption in the world. For this reason, energy-efficient buildings are currently the focus of both scientists and ordinary users. Contemporary buildings are much better thermally insulated, and existing buildings are subject to successive thermal modernization. Building partitions and the reduction in heat loss by way of transmission are still the focus of attention. However, it should be noted that the energy needed to prepare domestic hot water has a large share in the annual energy consumption of a building. The first section of the paper discusses the availability of water resources in the world. Then, the knowledge on daily water consumption in the European Union countries was reviewed and the relationship between water consumption and the demand for non-renewable primary energy calculated using the methodology of preparing energy certificates for buildings was discussed. On the basis of the literature review, the objectives of this study are presented in the last subsection of the introduction.

### 1.1. Water Resources in Poland and All over the World

Water resources around the world vary considerably. For example, water resources in Poland (average = 1600 m<sup>3</sup>/person) are very small compared to those in other European countries (average = 5000 m<sup>3</sup>/person), or even some African countries (average in Egypt = 2200 m<sup>3</sup>/person) [1]. In addition, water consumption in residential buildings has changed over the years. In Poland, it has fallen gradually since the end of the 1980s. Based on data from the Central Statistical Office [1], the water consumption in residential buildings in 1990 was on average 180 dm<sup>3</sup>/person/day. It was largest in large cities (with over 500,000 inhabitants), and smaller in cities with only 10,000–20,000 inhabitants. Over time, water consumption decreased, reaching an average value of 108 dm<sup>3</sup>/person/day in 2003, with 143 dm<sup>3</sup>/person/day in the largest cities, and 94 dm<sup>3</sup>/person/day in the smallest [2]. According to the Regulation of the Minister of Infrastructure, the average household water consumption currently ranges from 30 to 160 dm<sup>3</sup>/person/day [3] depending on the household equipment in sanitary facilities. The low value of 30 dm<sup>3</sup>/person/day corresponds to an apartment without a toilet or bathroom, which has water intake from its own source (i.e., no external water supply). The values between 80 and 100 dm<sup>3</sup>/person/day may correspond to an apartment with a bathroom, water supply, and local heat source, while higher values (up to 160 dm<sup>3</sup>/person/day) are distinguished by a hot water supply to the apartment, e.g., from a combined heat and power plant.

Because of the scarcity of water resources, efforts should be made to reduce water consumption across the globe. In the case of domestic hot water (DHW), the efficiency of heating and the share of renewable energy sources (RES) used for its preparation should also be increased.

### 1.2. Daily Domestic Hot Water Consumption in Residential Buildings—Research All over the World

It is estimated that the average consumption of DHW (55 °C) in residential buildings with standard equipment and tap points accounts for approximately 25% of the total water consumption [4]. A research group from Estonia estimated via calculations that the consumption of domestic hot water (50 °C) accounts for 40% of the total consumption of water [5]; however, it was later determined that this value may be too high. A study conducted in 1986 in the USA [6] revealed that the consumption of domestic hot water (58 °C) was 89 dm<sup>3</sup>/person/day, which was relatively high. Such research has been carried out for many years, during which time, water consumption has decreased in virtually every country. Studies from 2015 showed that DHW consumption in the USA decreased and based on the measurements, it was defined as 63.9 dm<sup>3</sup>/person/day [7]. Studies performed in South Africa have shown that the average consumption of hot water (65 °C) is 61–88 dm<sup>3</sup>/person/day [8], whereas in Canada, it was found to be significantly lower (43 dm<sup>3</sup>/person/day); however, elsewhere in Canada, the average water consumption per person was 59 dm<sup>3</sup>/person [9] and 60 dm<sup>3</sup>/person in [10]. Studies conducted in Finland [11] showed that DHW consumption was approximately 47.3 dm<sup>3</sup>/person/day, which confirmed the results of previous studies [12]. Additionally, in a report regarding Swedish consumption, Bagge and Johansson [13] determined the DHW consumption rate per area as 0.88–1.1 dm<sup>3</sup>/m<sup>2</sup>/day, and in China, there are values regarding daily consumption per apartment of 20–80 dm<sup>3</sup>/apartment/day [14]. In Latin America, research showed the value of DHW consumption as 78.5–102.9 dm<sup>3</sup>/person/day based on the number of people living in the apartment [15], while in Spain, this was 25.7 dm<sup>3</sup>/person/day [16].

Additional research on the consumption of domestic hot water was carried out in Poland by Szaflik [17]. It was estimated that in the years 2001–2002, the consumption of domestic hot water (50 °C) was 55 dm<sup>3</sup>/person/day. Subsequently, Janiszewska and Szaflik [18] analyzed the consumption of DHW over a period of 13 years in one Polish city. They determined that the average consumption of domestic hot water was 40.2 dm<sup>3</sup>/person/day. Furthermore, they estimated that the decreasing consumption of domestic hot water was related to the metering of domestic water consumption in residential

buildings and the more frequent use of a shower instead of a bathtub. Research conducted in an old multi-family building [19] indicated that the average DHW consumption in 13 flats was 43.3 dm<sup>3</sup>/person/day.

Additional analyses indicate that DHW consumption in the winter months may be up to 10% higher than in the summer months [20]. Lomet et al. [21] and Meyer [22] came to similar conclusions. The amount of consumed domestic hot water is influenced by the number of people in the apartment, their habits [19,23], and the population density [22].

Considering the published research on DHW consumption indices, it is clear that the determined values differ from each other, but the range can be defined as 40.2–88 dm<sup>3</sup>/person/day of 55 °C water. In the case of Poland, these indicators range from 40.2 to 58 dm<sup>3</sup>/person/day of 55 °C water. Such a wide range of values suggests that further research should focus on determining DHW consumption indicators in existing buildings; this point was emphasized in particular by Szuligowska-Zgrzywa et al. [19], as well as Bagge and Johansson [13].

Table 1 summarizes the results obtained by other authors with the indication of the method for determining the amount of domestic hot water used:

**Table 1.** Results of research on water consumption rates in residential buildings in the years 1986–2020.

Country	Reference	DHW Consumption	Method
USA 1986	1986 [6]	89 dm <sup>3</sup> /day/person	water meters/4 buildings, multi-family and single-family houses
South Africa	1996 [8]	61–89 dm <sup>3</sup> /day/person	water meters and water temperature/3 buildings
Poland	2011 [17]	55 dm <sup>3</sup> /day/person	water meters/6 buildings/about year
Canada	2013 [10]	60 dm <sup>3</sup> /day/person	water meters and oil consumption/1549 surveys
Spain	2014 [16]	25.7 dm <sup>3</sup> /day/person	water meters/10 apartments
North America	2015 [7]	63.9 dm <sup>3</sup> /day/person	water meters/69 apartments in 4 states/annual measurement
Canada	2015 [9]	59 dm <sup>3</sup> /day/person	cold water meters make up water for DWH tank/73 apartments/2–6 months measurements
Finland	2016 [10] 2017 [12]	47.3 dm <sup>3</sup> /day/person	domestic hot water meters/86 apartments (2.2 people)/9 months measurements
Latin America	2019 [15]	78.5–102.9 dm <sup>3</sup> /day/person	Survey with estimation of DHW consumption/90 houses/28 days
Poland	2020 [18]	40.2 dm <sup>3</sup> /day/person	domestic hot water meters/multi-family building (average 2 people per apartment)/14 years
Poland	2020 [19]	43.3 dm <sup>3</sup> /day/person	water meters, when available/4 multi-family buildings—13 apartments/3 months measurements
Estonia	2019 [5]	DHW to 40% total water consumption	the conversion of the quantities of heat delivered to heating up the water into the amount of DHW consumption
Szwecja	2011 [13]	0.88–1.1 dm <sup>3</sup> /day/m <sup>2</sup>	electricity consumption/72 apartments/7 days measurements
China	2016 [14]	20–80 dm <sup>3</sup> /day/apartment	water meters/multi-family buildings/year

The results presented in Table 1 show that the majority of research was conducted in multi-family buildings equipped with DHW meters. In this case, measuring of the total annual water consumption is not problematic. There is a lack of research in buildings that are not equipped with water meters for DHW, so there are no real DHW consumption rates. A method that will allow for non-invasive determination of the amount of water used is needed, because the installation of a water meter involves interference with the existing

installation. The research was carried out in measuring periods ranging from 7 days to a year (several months on average).

It should also be noted that over time, the measured DHW consumption decreased. This is due to people's greater awareness of resource and energy saving, and indicates the need to update data on water consumption.

### *1.3. Domestic Hot Water Consumption in the Context of Primary Energy Usage Calculated by Means of European Union Directive and Polish Legal Requirements*

Energy certification was introduced in European Union countries by the EU Directive in 2010 [24]. All member states have been obliged to perform energy assessments of buildings in terms of primary energy (PE). To determine the PE index, the energy demand of buildings for heating, ventilation, cooling, DHW, and lighting must be taken into account. The methodologies for calculating the PE index are typically based on the European standard, EN 13790. However, each country may introduce certain additional indicators describing the nature of buildings in that country. One such indicator is the consumption rate of domestic hot water. Energy certifications were introduced in Poland in 2008 [25], and DHW consumption was assumed to be 35 dm<sup>3</sup>/person/day for residential buildings and 48 dm<sup>3</sup>/day/person in multi-family buildings. Since 2014 [26], the value of the domestic hot water consumption unit has been 1.4 dm<sup>3</sup>/m<sup>2</sup>/day for single-family buildings and 1.6–2.0 dm<sup>3</sup>/m<sup>2</sup>/day for multi-family buildings. For comparison, in Estonia, the consumption of domestic hot water for the purposes of energy certification is 1.42 dm<sup>3</sup>/m<sup>2</sup>/day (i.e., 520 dm<sup>3</sup>/m<sup>2</sup>/year) [5]. The share of DHW in the annual energy consumption of a typical building is around 20% [27] or 24% [28].

Energy certifications and setting maximum values for all European Union countries aim to reduce energy consumption and increase the share of RES used to meet society's energy demands. By definition, energy certifications were intended to encourage investors to construct buildings with low energy consumption while simultaneously using energy-efficient heating, ventilation, and air conditioning (HVAC) systems. Having information about the actual PE indicator values, which take into account the preparation of DHW, it is possible to consider what restrictions should be introduced in legal regulations so that buildings truly use less energy. To obtain practical, valid results, it is necessary to measure real water consumption because DHW preparation constitutes a large portion of the building's energy demand. It is possible to reduce the energy consumption where it is most needed by maintaining the true relative proportions of energy consumption by individual systems of technical building equipment. For example, if hot water consumption is assumed to be unrealistically large, the influence of ventilation, lighting, and HVAC efficiency (and adjusting these parameters to the current needs) on the calculated energy usage can be insignificant. Nevertheless, their importance for the true energy effectiveness of the building is crucial.

In Poland, the maximum PE index for heating, ventilation and domestic hot water preparation from January 2021 should be less than 70 kWh/m<sup>2</sup>/year for residential buildings. This was a low target value, which may be difficult to achieve, especially if domestic hot water consumption is overestimated. As a result, investors may be forced to use economically ineffective solutions just to meet the imposed requirements. This can also lead to changes in the economy because such changes may favor the promotion of some systems at the expense of others (not rightly so). Therefore, such energy reductions comprise a sensitive topic from an economic standpoint.

### *1.4. Research Goal*

The aim of the current research was to determine the real consumption of domestic hot water in residential (single-family) buildings to enable more accurate (i.e., more realistic) calculations of the primary energy index, PE<sub>H+W</sub>. As has been shown, most of the DHW consumption indicators were determined in multi-family buildings equipped with a water meter. In single-family buildings, methods based on other measurements should be used, because this type of building usually does not have DHW water meters, and

their installation is an interference with the installation. The research aims to define the assessment method for buildings without DHW measuring devices, which can be based on a long period of time and on historical data. The study was based on analysis of natural gas consumption in three single-family buildings, where the owners recorded their gas consumption over four years. Based on the amount of gas consumed, we determined (i) the total energy necessary to heat hot water and (ii) the consumption rate of domestic hot water. These indicators were used to calculate the energy performance of the buildings to evaluate the various methodologies applied in European countries in terms of the real values for existing buildings.

Based on the literature review, the knowledge gap indicated a lack of studies that are comparing the real and theoretical (based on calculation) energy usage for domestic hot water preparation. Investigations carried out in this paper were conducted to assess it on the basis of three different (in depended) residential buildings. The novelty of the paper consists of the application of the hot water consumption assessment method based on historical consumption data, which is also possible to use in the case of absence of water meters counting DHW consumption. The new and valuable contribution of the paper to the field lies in the results, which revealed that the actual consumption of hot water may significantly differ from the consumption assumed in the calculations, imposed by the calculation methodology. Consequently, the picture of the computational energy performance of the building can be distorted and conclusions about the energy consumption of the building can be wrong or lead to wrong decisions regarding the choice of DHW system in combination with heating, ventilation and air conditioning systems. The presented results are intended to inspire similar analyses in other countries and for a larger number of buildings, in order to finally be able to verify the data for the calculations, which are imposed by the energy performance calculation methodologies (as well in the European Union and elsewhere in the world).

Determining the indicators for real domestic hot water consumption will allow for a better assessment of the total energy consumption, which will make it possible to implement more effective activities aimed at global energy consumption reduction.

## 2. Materials and Methods

This study was divided into two parts. The first part involved determining the amount of DHW and total required energy for heating DHW in existing buildings. The second part applied the calculated indicators to conduct energy assessments of the buildings and determine the PE indicators for six single-family houses.

By comparing the results obtained with various DHW consumption indicators, we determined (i) whether the DHW consumption had a significant impact on meeting the maximum PE requirements and (ii) the share of the total energy consumption that was used to prepare DHW.

### 2.1. Method for Determining DHW Consumption Based on Natural Gas Consumption

The amount of domestic hot water consumption can be assessed based on the monthly consumption of natural gas, which is determined from settlements with the gas supplier. The total consumption of natural gas in the heat source covers the needs of heating the building and preparing DHW. In the winter, natural gas is used for both purposes, but in the summer, the heat source in single-family houses is only used to prepare DHW. Knowing the amount of natural gas consumed during months when the heating system was shut down makes it possible to estimate the amount of heat required for heating hot water.

Studies determining DHW consumption based on energy carrier consumption are not common, but are present in the literature, such as the studies in [10], in which DHW consumption was estimated based on oil consumption. The share of oil consumption for heating purposes was estimated and this value was subtracted from the total oil consumption. In this study, the analysis will cover the months when it is certain that the energy carrier should be used only for DHW heating. The research in [29] determined the

amount of DHW based on the amount of heat supplied for DHW heating obtained in gas boilers, but the research concerned hospitals. In the research [30], analyses were carried out on gas consumption and isolating gas consumption at DHW. It was noticed that in the off-heating season, gas consumption is low and constant. However, the amount of DHW was not determined on this basis. The total energy used for water preparation was determined using information provided by the owners of the investigated buildings; then, the DHW consumption could be calculated.

The total energy for a given building/heat source can be determined based on the total amount of gas consumed throughout the year (or month) using Equation (1),

$$Q_F[\frac{\text{kWh}}{\text{year}}, \frac{\text{kWh}}{\text{month}}] = \frac{C \cdot W_0}{3.6} \quad (1)$$

where  $Q_F$  is the total energy for the heating source (kWh/year or kWh/month),  $C$  is the gas consumption of the heating source ( $\text{m}^3/\text{year}$  or  $\text{m}^3/\text{month}$ ), and  $W_0$  is the calorific value for natural gas,  $31 \text{ MJ}/\text{m}^3$  (data from WZG Poznań [31]).

## 2.2. Determining the Amount of Gas and Total Energy Required for Domestic Hot Water Purposes

To determine the total energy needed for DHW preparation without taking into account heating, the assumption was made that during the summer months, natural gas was used only for heating domestic hot water.

A set of natural gas quantities consumed each month ( $C_{1-12}$ ) was compiled for each building, and the months in which there was no heating and no long holidays (i.e., breaks in DHW consumption) were specified. Based on the gas consumption for the selected months, the average monthly consumption of natural gas used for heating domestic hot water was determined. This analysis assumed that the consumption of gas for heating DHW during the summer period would be similar to that throughout the year. This is a simplifying assumption, because the seasonality of domestic hot water consumption has not been tested, but it was also noted in [16,32].

A simplified diagram of the energy determination is shown in Figure 1.

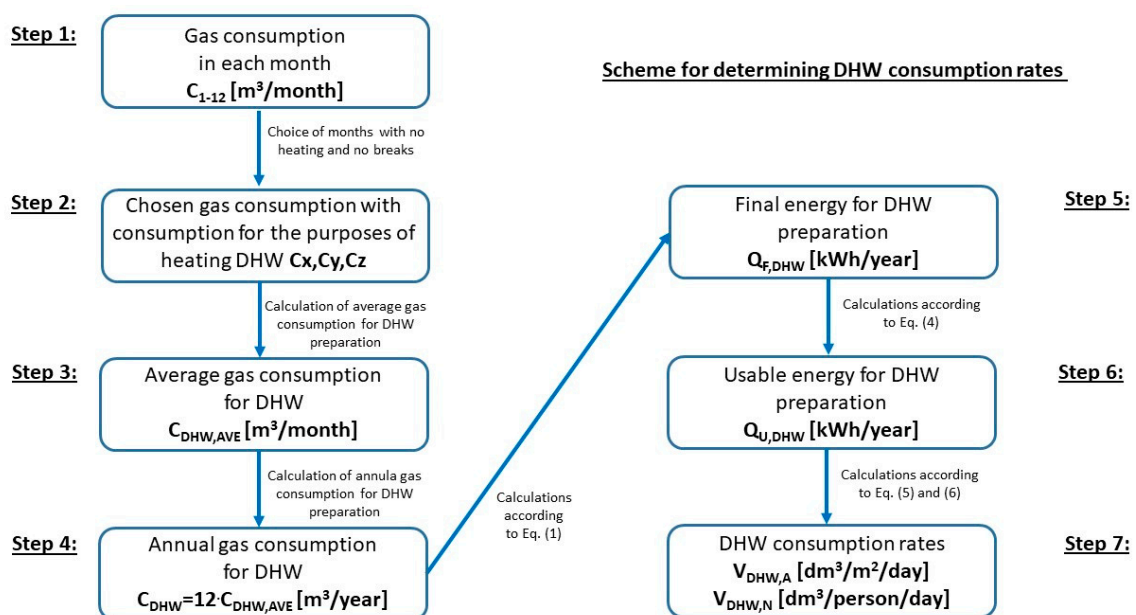


Figure 1. Scheme for determining DHW consumption rates.

The total energy for domestic hot water preparation ( $Q_{F,W}$ ), taking into account the calorific value of fuel, represents the amount of energy carrier that must be used to heat

the water to a certain temperature. This parameter also accounts for the amount of heated water used and the efficiency of the DHW system.

The amount of domestic hot water can be determined based on the usable energy value,  $Q_{U,W}$ . The formulas for calculating the usable energy are presented in Equation (2), which is related to the water consumption rate per square meter of building area, and Equation (3), which is related to the number of people living in the building.

$$Q_{U,W,A} \left[ \frac{\text{kWh}}{\text{month}} \right] = \frac{V_{DHW,A} \cdot A_f \cdot (t_{DHW} - t_w) \cdot \rho \cdot c_w \cdot t_M \cdot k_R}{3600} \quad (2)$$

$$Q_{U,W,N} \left[ \frac{\text{kWh}}{\text{month}} \right] = \frac{V_{DHW,N} \cdot N \cdot (t_{DHW} - t_w) \cdot \rho \cdot c_w \cdot t_M \cdot k_R}{3600} \quad (3)$$

$V_{DHW,A}$ —daily demand for DHW related to the area, ( $\text{dm}^3/\text{m}^2/\text{day}$ );

$V_{DHW,N}$ —daily demand for DHW related to number of people  $N$  ( $\text{dm}^3/\text{person}/\text{day}$ );

$A_f$ —area of the heated building ( $\text{m}^2$ );

$N$ —number of people (person);

$t_{DHW}$ —designated temperature of DHW in the tap, according to the settings of the heat source ( $55^\circ\text{C}$ );

$t_w$ —designated temperature before heating ( $10^\circ\text{C}$ );

$\rho$ —density of water (assumed to be  $1 \text{ kg}/\text{dm}^3$ );

$c_w$ —specific heat of water (assumed to be  $4.19 \text{ kJ}/(\text{kg}\cdot\text{K})$ );

$k_R$ —correction factor to account for interruptions in the DHW usage (0.9), based on the methodology in [23], assuming that in residential buildings, residents are present 90% of the time;

$t_M$ —number of days in the month (30 or 31 days).

The usable energy is the final required energy, taking into account the efficiency of the installation. The formula for converting final energy into usable energy is presented in Equation (4):

$$Q_U \left[ \frac{\text{kWh}}{\text{year}}; \frac{\text{kWh}}{\text{month}} \right] = Q_F \cdot \eta_{\text{tot}} \quad (4)$$

The efficiency of a heating installation with a heat source, such as a gas condensing dual-function boiler, can be assumed at the level of 90% for a heating installation and 60% for an installation used to prepare DHW according to the methodology applied in Poland [26].

### 2.3. Converting the Final Energy into the Amount of Hot Water

Considering Equations (2) and (3), it is possible to obtain the parameters for calculating the amount of DHW per square meter of the building (Equation (5)) and per person (Equation (6)):

$$V_{DHW,A} \left[ \frac{\text{dm}^3}{\text{m}^2 \cdot \text{day}} \right] = \frac{Q_{U,W,A} \cdot 3600}{A_f \cdot (t_{DHW} - t_w) \cdot \rho \cdot c_w \cdot t_M \cdot k_R} \quad (5)$$

$$V_{DHW,N} \left[ \frac{\text{dm}^3}{\text{person} \cdot \text{day}} \right] = \frac{Q_{U,W,N} \cdot 3600}{N \cdot (t_{DHW} - t_w) \cdot \rho \cdot c_w \cdot t_M \cdot k_R} \quad (6)$$

Equations (5) and (6) take into account the usable energy applied for the purpose of heating DHW, as determined by Equation (4).

Based on the amount of gas consumed in the building (calculated from Equations (1)–(6)), it is possible to determine the final energy ratio for domestic hot water heating ( $Q_{F,W}$ ), the DHW consumption rate in relation to the area ( $V_{DHW,A}$ ), and the DHW consumption rate per inhabitant ( $V_{DHW,N}$ ).

#### 2.4. Real Buildings Assessed in This Study

To determine the consumption of hot water in single-family houses, the cold water and gas consumption readings from three single-family houses were analyzed. The values obtained from the building owners covered the years 2016–2019. The readings included gas consumption, annual water consumption, and length of the heating season. Three single-family buildings were selected for the analysis, as single-family housing constitutes about 80% of all apartments in Poland. The usable area of the analyzed buildings is 100–122.5 m<sup>2</sup>, and the average usable area of the existing residential building was 107.78 m<sup>2</sup>, according to the data from the 2011 national population and housing census [33] (the census takes place every 10 years).

A summary of the data collected for the analyzed buildings is provided here. Three real single-family residential buildings with similar surface areas (100–122.5 m<sup>2</sup>) and heat sources (i.e., combined gas boiler) were selected for the analysis (Table 2). Additionally, the number of people inhabiting each building was similar: two adults with children in building 1 (B1), and buildings 2 and 3 (B2 and B3) housed three people. Figures 2–4 show the monthly gas consumption values obtained from the owners of B1–B3, respectively.

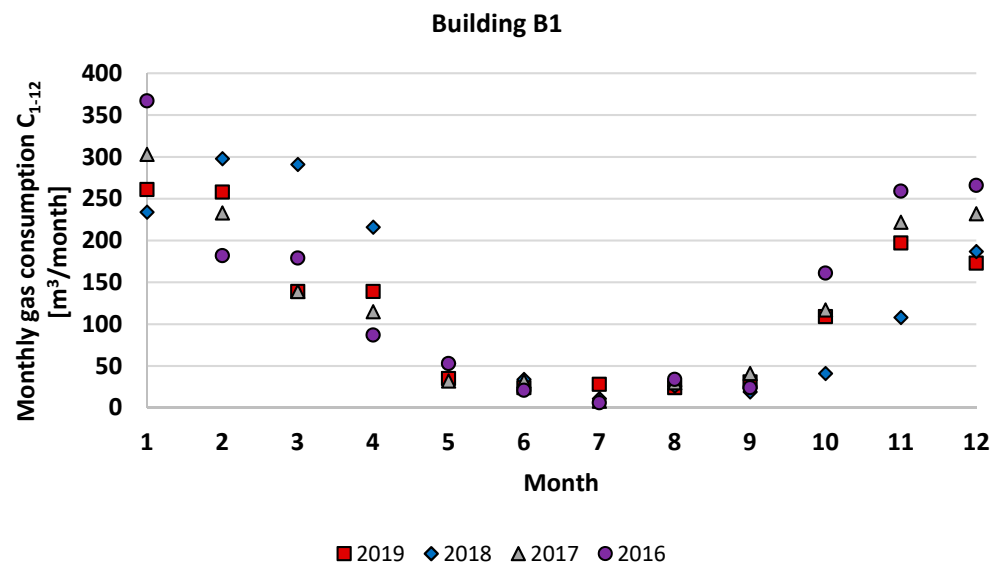


Figure 2. Monthly gas consumption in building B1.

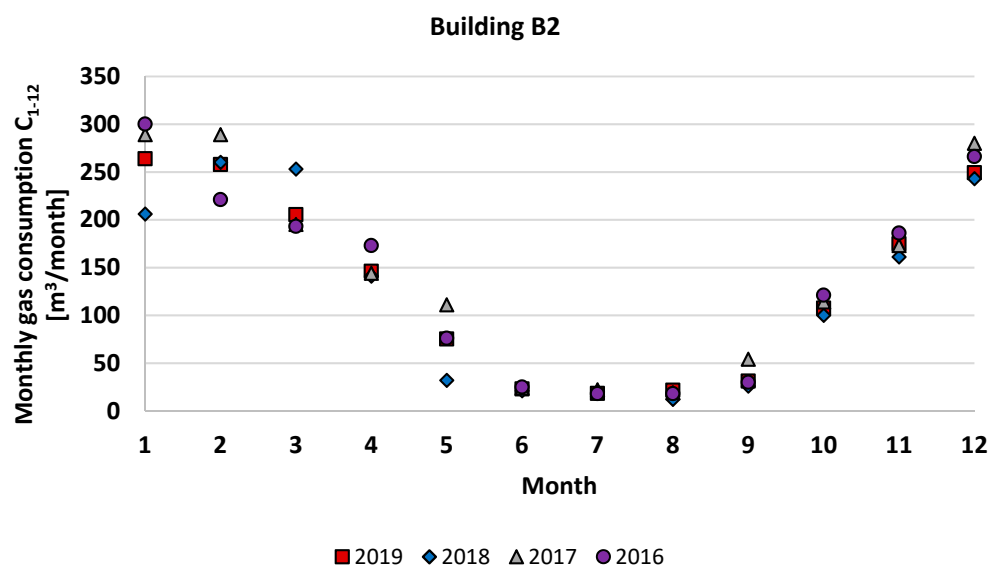


Figure 3. Monthly gas consumption in building B2.

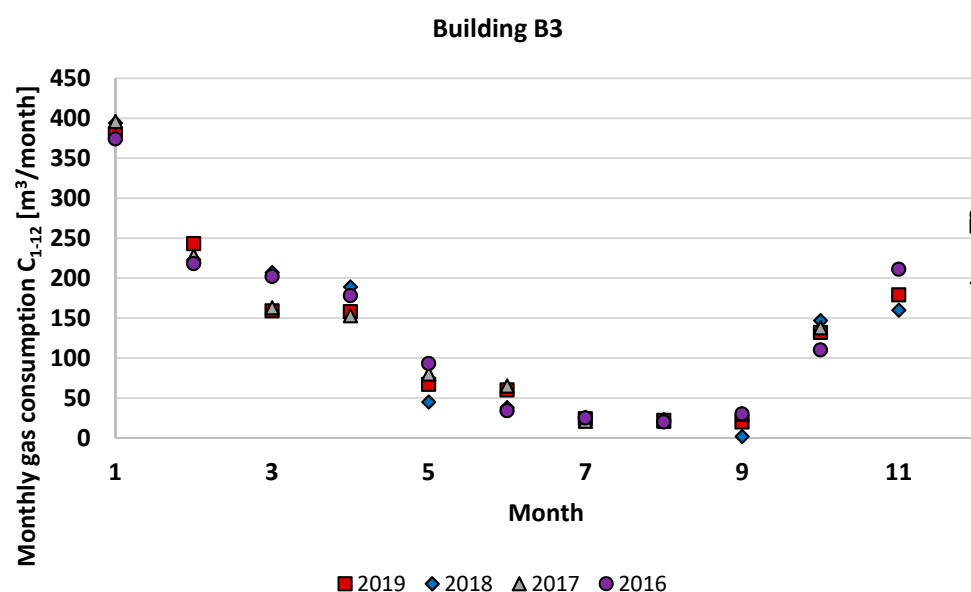


Figure 4. Monthly gas consumption in building B3.

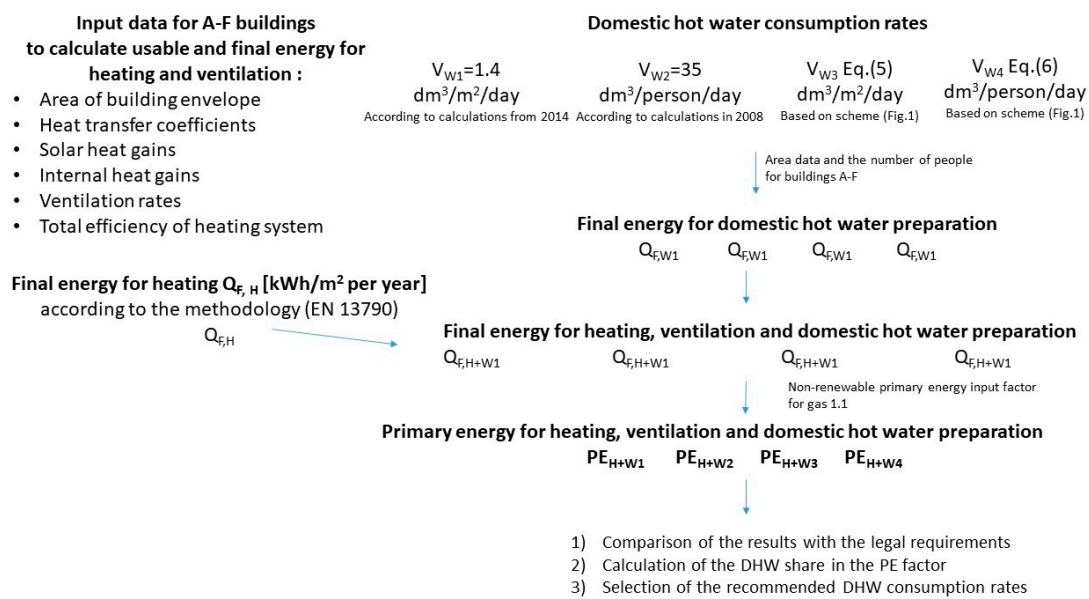
Table 2. Specifications of the three investigated buildings.

	Building B1	Building B2	Building B3
Heat source	Combined gas boiler	Combined gas boiler	Combined condensing gas boiler
Area of the building	122.5 m <sup>2</sup>	100 m <sup>2</sup>	100 m <sup>2</sup>
Number of people	4	3	3
List of water intake points	kitchen sink 2 sinks 2 toilet bowls bath shower dishwasher washing machine	kitchen sink 2 sinks 2 toilet bowls bath shower dishwasher washing machine	kitchen sink 2 sinks 2 toilet bowls bath shower dishwasher washing machine
Annual gas consumption	2019: 1423 m <sup>3</sup> 2018: 1496 m <sup>3</sup> 2017: 1526 m <sup>3</sup> 2016: 1632 m <sup>3</sup>	2019: 1061 m <sup>3</sup> 2018: 1455 m <sup>3</sup> 2017: 1714 m <sup>3</sup> 2016: 1551 m <sup>3</sup>	2019: 1249 m <sup>3</sup> 2018: 1319 m <sup>3</sup> 2017: 1714 m <sup>3</sup> 2016: 1321 m <sup>3</sup>
Annual water consumption	2019: 125 m <sup>3</sup> 2018: 127 m <sup>3</sup> 2017: 124 m <sup>3</sup> 2016: 136 m <sup>3</sup> Average: 128 ± 5.5 m <sup>3</sup>	2019: 68 m <sup>3</sup> 2018: 71 m <sup>3</sup> 2017: 81 m <sup>3</sup> 2016: 69 m <sup>3</sup> Average: 79 ± 12.6 m <sup>3</sup>	2019: 135 m <sup>3</sup> 2018: 141 m <sup>3</sup> 2017: 1134 m <sup>3</sup> 2016: 129 m <sup>3</sup> Average: 135 ± 4.9 m <sup>3</sup>

### 2.5. Building Energy Assessments and Input Data

The determined indicators concerning the DHW consumption and final energy used for DHW purposes were used to calculate the PE indices based on the methodology for calculating energy performance described in the Minister's Regulation (for Poland) [26]. The same methodology was applied in the analyses described previously [34–36].

A scheme depicting how the four indicators were determined based on the values for real buildings is shown in Figure 5.



**Figure 5.** Diagram for calculating the energy rating and the impact of various water consumption indicators on the calculated PE indices.

The determined indicators were then used to calculate the final and primary energy for six single-family houses. The list of buildings and detailed analyses are presented in Section 3.2.

### 3. Results

#### 3.1. DHW Consumption Rates and Final Energy Indices for Real Buildings B1–B3

##### 3.1.1. Building B1

For building B1, domestic hot water consumption indicators and final energy for domestic hot water preparation were determined using the calculation scheme shown in Figure 1. Table 3 summarizes the calculation results for individual steps in the algorithm for determining the amount of domestic hot water.

**Table 3.** Determination of DHW consumption indicators for building B1 (according to the diagram in Figure 1).

Month	Step 1					Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	
	Gas Consumption $C_{1-12}$					Gas Consumption for DHW	Average		Final Energy for DHW	Usable Energy for DHW	DHW Consumption Rate	
	2016	2017	2018	2019	Average		$C_{DHW,AVE}$	$C_{DHW}$	$Q_{E,DHW}$	$Q_{U,DHW}$	$V_{DHW,A}$	$V_{DHW,N}$
						[m <sup>3</sup> /Month]	[m <sup>3</sup> /Year]	[kWh/Year]	[kWh/Year]	[dm <sup>3</sup> /m <sup>2</sup> /Day]	[dm <sup>3</sup> /Person/Day]	
1	367	303	234	261	291	–						
2	182	233	298	258	243	–						
3	179	139	291	139	187	–						
4	87	115	216	139	139	–						
5	53	32	53	35	43	–						
6	21	32	34	24	28	28						
7	6	8	11	28	13	Holidays	28.6	343	2954	1772	0.84	25.8
8	34	30	26	24	29	29						
9	24	41	19	31	29	29						
10	161	117	41	109	107	–						
11	259	222	108	197	197	–						
12	266	232	187	173	215	–						

For building B1, July was the holiday month, so the gas consumption data for this month were not taken into account. The average consumption of gas from June, August, and September was assumed to represent the other months.

Using the calculation scheme described above, the following indicator values were calculated:  $V_{DHW,A} = 0.84 \text{ dm}^3/\text{m}^2/\text{day}$ ;  $V_{DHW,N} = 25.8 \text{ dm}^3/\text{person}/\text{day}$ .

### 3.1.2. Building B2

For building B2, the DHW consumption indicators and final energy for DHW preparation were also determined using the calculation scheme shown in Figure 1. Table 4 summarizes the results for the individual steps in the algorithm for determining the amount of domestic hot water.

**Table 4.** Determination of DHW consumption indicators for building B2 (according to the diagram in Figure 1).

Month	Step 1					Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	
	Gas Consumption $C_{1-12}$					Gas Consumption for DHW	Average		Final Energy for DHA	Usable Energy for DHW	DHW Consumption Rate	
	2016	2017	2018	2019	Average		$C_{DHW,AVE}$	$C_{DHW}$	$Q_{E,DHW}$	$Q_{U,DHW}$	$V_{DHW,A}$	$V_{DHW,N}$
						[m <sup>3</sup> /Month]	[m <sup>3</sup> /Year]	[kWh/Year]	[kWh/Year]	[dm <sup>3</sup> /m <sup>2</sup> /Day]	[dm <sup>3</sup> /Person/Day]	
1	300	289	206	260	264	–						
2	221	289	260	261	258	–						
3	193	195	253	180	205	–						
4	173	144	141	126	146	–						
5	76	111	32	82	75	–						
6	25	24	21	22	23	23						
7	18	22	20	13	18	18	23.4	281	2423	1454	0.84	28.2
8	18	19	12	38	22	22						
9	30	–	26	38	31	31						
10	121	114	100	95	108	–						
11	186	173	161	179	175	–						
12	266	280	243	208	249	–						

DHW consumption in building B2 was determined from June to September, without considering September 2017, because during this month, the heat was turned on earlier than usual.

Using the scheme presented in Figure 1, the following DHW consumption indicators were calculated:  $V_{DHW,A} = 0.84 \text{ dm}^3/\text{m}^2/\text{day}$ ;  $V_{DHW,N} = 28.2 \text{ dm}^3/\text{person}/\text{day}$ .

### 3.1.3. Building B3

For building B3, the DHW consumption indicators and final energy for DHW preparation were also determined using the calculation scheme shown in Figure 1. Table 5 summarizes the results for the individual steps in the algorithm for determining the amount of domestic hot water.

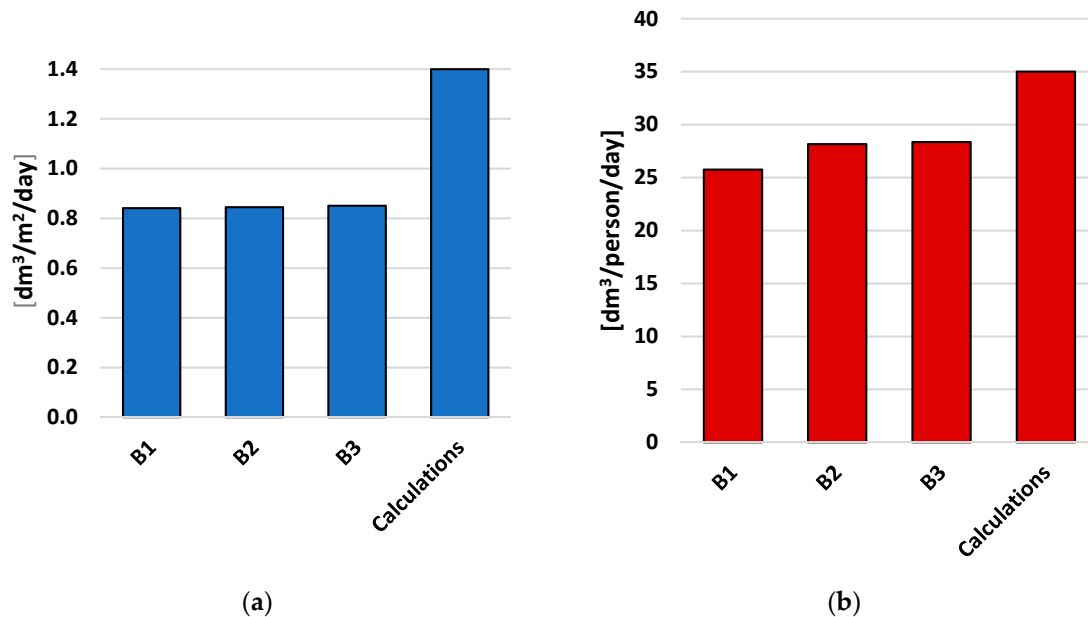
The gas readings in building B3 were recorded every two months, and the gas consumption during the period from June to September was assumed for the calculations. Using the scheme in Figure 1, the following DHW consumption indicators were calculated:  $V_{DHW,A} = 0.85 \text{ dm}^3/\text{m}^2/\text{day}$ ;  $V_{DHW,N} = 28.3 \text{ dm}^3/\text{person}/\text{day}$ .

**Table 5.** Determination of DHW consumption indicators for building B3 (according to the diagram in Figure 1).

Month	Step 1					Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	
	Gas Consumption $C_{1-12}$					Gas Consumption for DHW	Average		Final Energy for DHA	Usable Energy for DHW	DHW Consumption Rate	
	2016	2017	2018	2019	Average		$C_{DHW,AVE}$	$C_{DHW}$	$Q_{E,DHW}$	$Q_{U,DHW}$	$V_{DHW,A}$	$V_{DHW,N}$
						[m <sup>3</sup> /Month]	[m <sup>3</sup> /Year]	[kWh/Year]	[kWh/Year]	[dm <sup>3</sup> /m <sup>2</sup> /Day]	[dm <sup>3</sup> /Person/Day]	
1	374	396	394	380	386	–						
2	218	228	223	243	228	–						
3	202	163	207	159	183	–						
4	178	153	189	158	170	–						
5	93	80	45	67	71	–						
6	34	65	38	60	49	–						
7	25	21	26	24	24	24	23.6	283	2437	1462	0.85	28.3
8	20	21	23	22	22	22						
9	30	30	22	20	25	25						
10	110	138	147	132	132	–						
11	211	217	160	179	192	–						
12	279	282	194	265	255	–						

### 3.1.4. Average Domestic Hot Water Consumption Rates

The calculated DHW consumption rates for the three analyzed buildings are presented in the charts in Figure 6; Figure 6a shows the results in relation to the building area, and Figure 6b shows the results in relation to the number of inhabitants. For comparison, these plots also show the relevant values obtained in the buildings' energy certifications (in Poland) [26].



**Figure 6.** Results of DHW consumption rate calculations compared with the values obtained when calculating the energy ratings of buildings in Poland. (a) Domestic hot water consumption in real buildings; (b) Domestic hot water consumption in real buildings

The results obtained from the calculations for the three analyzed buildings were significantly lower than those obtained from the energy assessment of buildings in Poland, which

is  $1.4 \text{ dm}^3/\text{m}^2/\text{day}$  now [26]. Based on the average value obtained for these buildings, the DHW consumption index ( $V_{\text{DHW,A}}$ ) was calculated to be  $0.85 \pm 0.005 \text{ dm}^3/\text{m}^2/\text{year}$ . This value was almost 40% lower than that assumed based on the energy rating of buildings. By relating the amount of hot water consumed to the area of the dwelling, the obtained ratio ( $V_{\text{DHW,A}} = 27.4 \pm 1.4 \text{ dm}^3/\text{person}/\text{day}$ ) was 22% lower than that found in the 2008 energy assessment, which was  $35 \text{ dm}^3/\text{person}/\text{day}$  [25].

The indicators relating water use to the number of people living in a building are more intuitive, since it is the people, not the area, that consume the water. The area indicator is often used because it is easier to integrate into calculations for new buildings with an unknown number of future inhabitants. Most of the studies and results summarized in Table 1 are showing DHW consumption per person. The same area may be inhabited by a different number of people who will consume a certain amount of water, regardless of the area they inhabit. When using indicators of water consumption per area, it will not reflect reality, so the necessity to determine DHW consumption indicators per person living in a single-family building was assumed. The analyzed buildings all had similar equipment, but different numbers of people. User behavior also influences water consumption, so this aspect must be analyzed further.

### 3.2. Primary Energy Indicators with Different Water Consumption Values

The PE indices were analyzed in the context of the determined DHW consumption values for six buildings. For each building, the value of the total energy required for heating and ventilation was determined (i.e., the final energy). This analysis included buildings with a heated surface ranging from 80 to  $160 \text{ m}^3$  and heat transfer coefficients that were compliant with the Polish requirements for new buildings [37]; specifically,  $U$  for an external wall ( $0.18 \text{ W}/(\text{m}^2\text{K})$ ), for the floor ( $0.30 \text{ W}/(\text{m}^2\text{K})$ ), and for windows ( $0.90 \text{ W}/(\text{m}^2\text{K})$ ). The heat losses through transmission and ventilation were calculated in accordance with the applicable standards, and Table 5 shows the values of the heat loss coefficients ( $\text{W}/\text{K}$ ). The final energy and useful energy values for each building were calculated according to a previously described method [26]. The final energy values were determined for each building by considering its heated area and the assumed number of people depending on the usable area. The calculations were based on the water consumption values obtained from the energy assessment methodology and determined in the tests described herein.

The PE indicators for each building accounted for heating, ventilation, and four different energy values for domestic hot water preparation determined by Equations (1)–(6). For each building, it was determined whether the building fulfilled the requirements for the maximum PE index ( $<70 \text{ W}/\text{m}^2/\text{year}$ ), and the share of energy demand for domestic hot water preparation was calculated in terms of the total PE index for the building. Table 6 summarizes the input data for the analyzed buildings.

Table 6. Summary of the data for the analyzed buildings.

	Heated Area (Floor Area)	Number of People	Transmission Heat Loss Coefficient	Ventilation Heat Loss Coefficient	Usable Energy for Heating	Final Energy for Heating
	$A_f$	N	$H_{\text{TR}}$	$H_{\text{TE}}$	$Q_{\text{U,H}}$	$Q_{\text{F,H}}$
Building	$[\text{m}^2]$	[Person]	$[\text{W}/\text{K}]$	$[\text{W}/\text{K}]$	$[\text{kWh}/\text{m}^2/\text{Year}]$	$[\text{kWh}/\text{m}^2/\text{Year}]$
A	160	5	75	82	31.2	34.7
B	130	4	70	67	36.5	40.6
C	158	5	81	81	34.6	38.4
D	151	4	68	77	29.7	33.0
E	114	3	60	58	35.5	39.4
F	80	3	40	41	33.7	37.4

### 3.2.1. New Buildings—Low U-Factors

The primary energy indices were calculated for the six analyzed single-family houses (A–F) presented in Table 6, while taking into account the demand for heating and ventilation, as well as the preparation of DHW. The calculations were performed in accordance with the diagram shown in Figure 5. The  $PE_{H+W1}$  indicator applied a unit value of  $1.4 \text{ dm}^3/\text{m}^2/\text{day}$  to calculate the primary energy for domestic hot water preparation; the  $PE_{H+W2}$  indicator was calculated using the value of  $35 \text{ dm}^3/\text{person}/\text{day}$ ; the  $PE_{H+W3}$  index designated for the existing buildings was  $0.85 \text{ dm}^3/\text{m}^2/\text{day}$ ; and the  $PE_{H+W4}$  index was  $27.4 \text{ dm}^3/\text{person}/\text{day}$ .

The results of the calculations for the analyzed buildings based on an energy-efficient standard with low transmission heat loss indicators (meeting Polish legal requirements) are summarized in Table 7. Green cells designate values that meet the legal requirements in terms of the maximum value of the non-renewable primary energy index for heating, ventilation, and DHW preparation in Poland (i.e.,  $PE_{H+W} = 70 \text{ kWh}/\text{m}^2/\text{year}$ ), and the higher values are shown in red.

**Table 7.** Calculated primary energy indicators obtained by applying various DHW consumption indicators for new buildings.

Building	Heated Area (Floor Area)	Number of People	Primary Energy Index for Heating, Ventilation, and Domestic Hot Water Preparation			
	$A_f$ [m <sup>2</sup> ]	N [Person]	$PE_{H+W1}$	$PE_{H+W2}$	$PE_{H+W3}$	$PE_{H+W4}$
			[kWh/m <sup>2</sup> /Year]			
A	160	5	76	68	61	61
B	130	4	82	74	67	67
C	158	5	80	72	65	66
D	151	4	74	61	59	56
E	114	3	81	68	66	63
F	80	3	81	79	66	71
		$PE_{H+W,average}$	79	70	64	64

The maximum value of the  $PE_{H+W}$  ratio for new buildings should be lower than  $70 \text{ kWh}/\text{m}^2/\text{year}$ . Buildings with water consumption indicators determined in this research (i.e.,  $PE_{H+W3}$  and  $PE_{H+W4}$  indicators) all met this requirement; the average value of the PE index was  $64 \text{ kWh}/\text{m}^2/\text{year}$ . Assuming the typical indicator for Poland in 2008–2014 (DHW consumption =  $35 \text{ dm}^3/\text{person}/\text{day}$ ), the PE ratio met the requirements in half of the buildings analyzed in this work; the average value was  $PE_{H+W2} = 70 \text{ kWh}/\text{m}^2/\text{year}$ . In the case where the indicator of  $1.4 \text{ dm}^3/\text{m}^2/\text{year}$  was used, none of the analyzed buildings met the requirements; the average value of this indicator was  $79 \text{ kWh}/\text{m}^2/\text{year}$ .

The calculations for each building were performed while considering identical heat loss from transmission and ventilation. Therefore, the architecture, the heated area, and any parameters describing the external areas of the building did not change. The actual acceptance of the DHW consumption values led to results that met the legal requirements. However, applying high DHW consumption in the calculations meant that investors would incur higher costs related to insulating buildings in order to lower their heat transfer coefficients so they meet the requirement of  $PE < 70 \text{ kWh}/\text{m}^2/\text{year}$ . Because the requirements for thermal insulation have been very high for a long time, adding insulation does not have a significant effect. It is also not conducive to a sustainable economy because the production, transport, and long-term use of large quantities of insulation materials may be harmful to the environment and reduce the energy gains from their use.

To assess the impact of the multiplicity of DHW consumption on the determined primary energy demand, the calculations were performed with various values of heat

losses by transmission. As a result, the condition for PE was achieved with a DHW consumption index of  $1.4 \text{ dm}^3/\text{m}^2/\text{year}$ . The overall results of these calculations are shown in Table 8.

**Table 8.** Primary energy indices for six buildings determined with heat losses meeting Polish requirements (DHW consumption =  $1.4 \text{ dm}^3/\text{m}^2/\text{day}$ ).

	Heated Area (Floor Area)	Number of People	Transmission Heat Loss Coefficient	Ventilation Heat Loss Coefficient	Usable Energy for Heating	Final Energy for Heating	Primary Energy for Heating, Ventilation, and Domestic Hot Water Preparation
	$A_f$	N	$H_{TR}$	$H_{TE}$	$Q_{U,H}$	$Q_{E,H}$	$PE_{H+W1}$
	[m <sup>2</sup> ]	[People]	[W/K]	[W/K]		[kWh/m <sup>2</sup> /Year]	
A	160	5	60	82	26.0	28.9	70
B	129.9	4	52	67	26.3	29.2	70
C	158	5	60	81	26.4	29.3	70
D	151	4	58	77	26.5	29.4	70
E	114	3	47	58	26.2	29.1	70
F	80	3	40	41	26.3	29.2	70

To obtain a  $PE_{H+W}$  value of  $70 \text{ kWh}/\text{m}^2/\text{year}$ , the heat loss through transmission would need to be reduced by 22%. The same effect (i.e., obtaining a  $PE_{H+W}$  index  $\leq 70 \text{ kWh}/\text{m}^2/\text{year}$ ) would enable the use of the real value of DHW consumption for the calculations. Additionally, the building owner would not incur additional costs associated with insulating the building with a thicker layer of insulation or installing windows with much better thermal parameters.

### 3.2.2. Existing Buildings—Meeting the Requirements before 2021

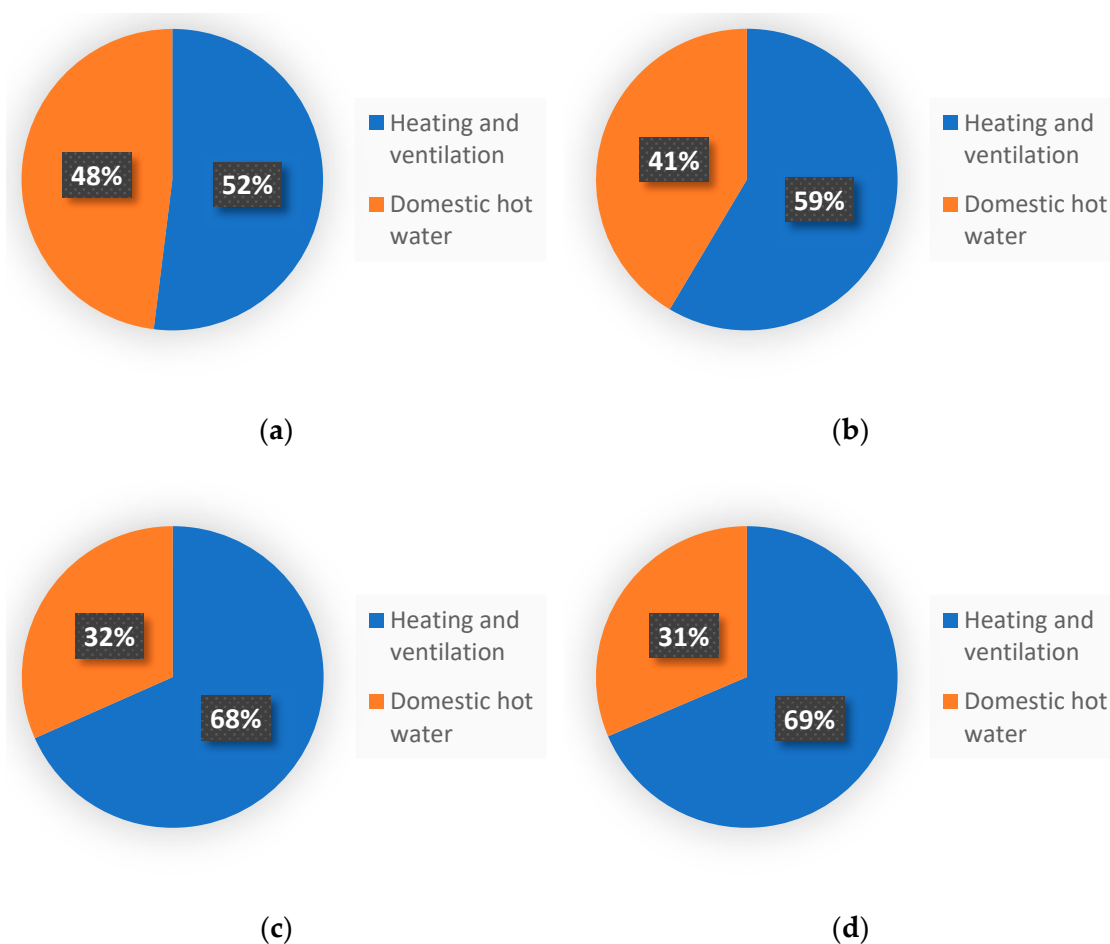
Calculations were also performed for existing buildings, which typically have higher heat losses through transmission. In existing buildings, the usable energy for heating and ventilation is about 35% higher than in new buildings. Before 2021, the requirements for the  $PE_{H+W}$  value in Poland amounted to  $95 \text{ kWh}/\text{m}^2/\text{year}$ . Therefore, the calculations were performed using higher heat transfer coefficients that would still allow the achievement of  $PE_{H+W} < 95 \text{ kWh}/\text{m}^2/\text{year}$  for real domestic hot water consumption rates. The values indicated the share of the primary energy demand for domestic hot water in the total primary energy demand of the building. In Table 9 green cells designate values that meet the legal requirements in terms of the maximum value of the non-renewable primary energy index for heating, ventilation, and DHW preparation for buildings build in 2017–2020 in Poland (i.e.,  $PE_{H+W} = 95 \text{ kWh}/\text{m}^2/\text{year}$ ), and the higher values are shown in red.

### 3.2.3. Share of a Building's Total Primary Energy Demand for Domestic Hot Water

The data obtained from the calculations shown in Tables 7 and 9 are presented graphically in Figures 7 and 8, which reveals the share of energy consumption used for heating/ventilation and domestic hot water. These graphs show four situations, which were calculated using different DHW consumption indicators. The results indicate that the consumption of domestic hot water accounts for between 31% and 48% of the total energy consumption. The largest proportion was obtained when adopting a water consumption rate of  $1.4 \text{ dm}^3/\text{m}^2/\text{day}$ . These indicators apply to buildings with specific thermal parameters, e.g., energy-efficient buildings.

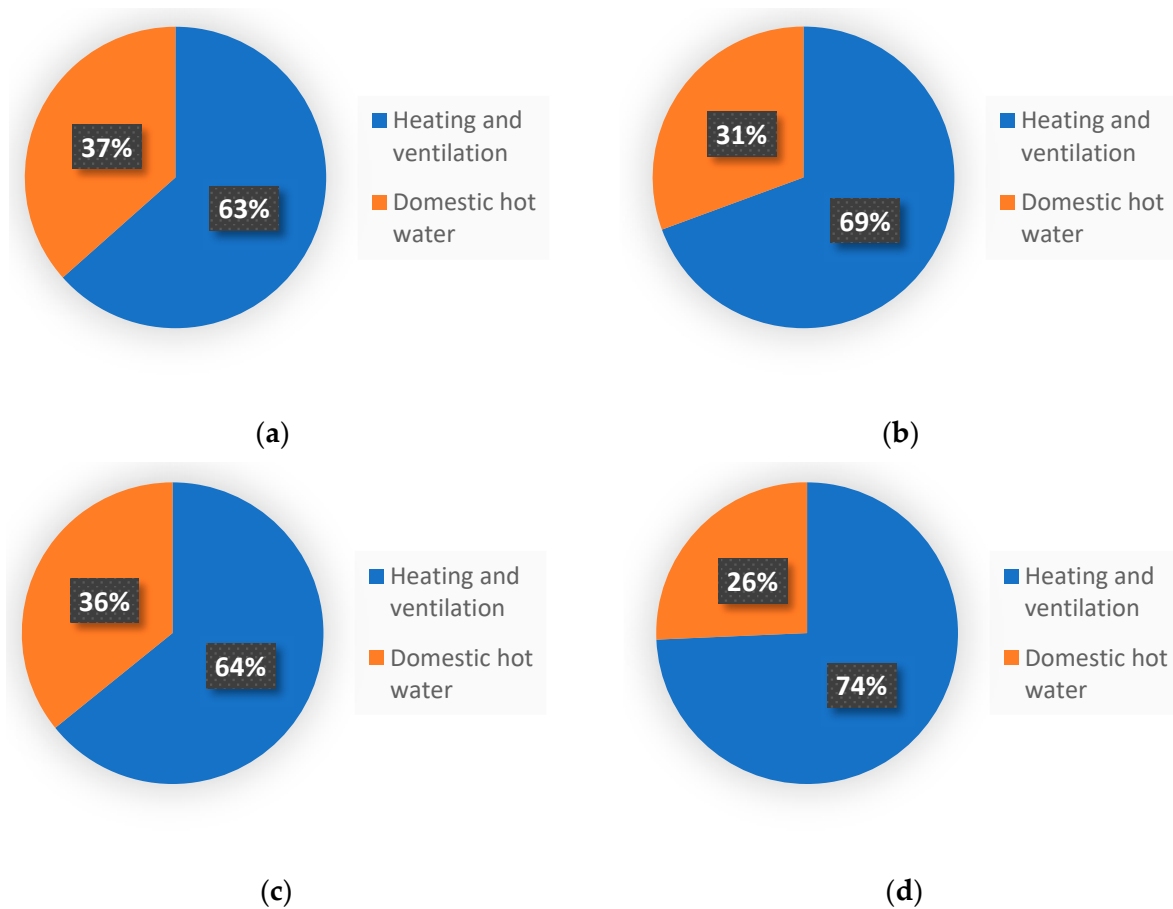
**Table 9.** Primary energy indicators obtained using various DHW consumption indicators for existing buildings.

	Heated Area (Floor Area)	Number of People	Transmission Heat Loss Coefficient	Ventilation Heat Loss Coefficient	Primary Energy Index for Heating, Ventilation, and Domestic Hot Water Preparation							
					$A_f$	N	$H_{TR}$	$H_{TE}$	$PE_{H+W1}$	$PE_{H+W2}$	$PE_{H+W3}$	$PE_{H+W4}$
					[m <sup>2</sup> ]	[Person]	[W/K]	[W/K]	[kWh/m <sup>2</sup> /Year]			
A	160	5	113	82	102	93	87	87				
B	129.9	4	105	67	110	101	95	95				
C	158	5	122	81	109	101	94	94				
D	151	4	102	77	98	86	83	80				
E	114	3	90	58	106	93	91	88				
F	80	3	60	41	97	94	82	87				
Average:					104	95	89	88				



**Figure 7.** The share of primary energy demand used for DHW and heating/ventilation in new buildings. Calculations were performed to meet the requirement of  $PE < 70$  kWh/m<sup>2</sup>/year using four different DHW consumption indicators. (a) DHW consumption: 1.4 dm<sup>3</sup>/m<sup>2</sup>/day; (b) DHW consumption: 35 dm<sup>3</sup>/person/day; (c) DHW consumption: 0.85 dm<sup>3</sup>/m<sup>2</sup>/day; (d) DHW consumption: 27.4 dm<sup>3</sup>/person/day.

In older existing buildings with worse thermal insulation parameters, the same domestic hot water consumption rates required a different share of the total demand for primary energy, i.e., 26–37%, which was approximately 10% less than in new buildings (Figure 8).



**Figure 8.** The share of primary energy demand used for DHW and heating/ventilation in older buildings with worse thermal insulation parameters. Calculations were performed to meet the requirement of PE < 95 using four different DHW consumption rates (the same rates as for the new building calculations). (a) DHW consumption: 1.4 dm<sup>3</sup>/m<sup>2</sup>/day; (b) DHW consumption: 35 dm<sup>3</sup>/person/day; (c) DHW consumption: 0.85 dm<sup>3</sup>/m<sup>2</sup>/day; (d) DHW consumption: 27.4 dm<sup>3</sup>/person/day

The analyses discussed above show that DHW consumption is critically important in terms of the energy balance in new buildings, owing to the increasingly better performance of the external casing and the potential future use of mechanical ventilation systems with heat recovery. The more important it becomes to use real domestic hot water consumption indicators for energy assessments of buildings, the more domestic hot water consumption will be reduced because of the better environmental awareness of society. Additionally, it is worth noting that the indicators obtained for buildings constructed before 2021 have better compliance with the values provided in the literature (20–24%) because the published analyses were conducted for existing buildings, not new ones.

#### 4. Discussion

The DHW consumption determined in this study was generally lower than in the energy assessments of buildings in Poland, as well as in other countries, e.g., Estonia [5], USA [6,7], South Africa [8], Canada [9], Scandinavia [11,13] and Latin America [15]. The reason may be that the referenced studies were conducted in multi-family buildings, where water consumption is usually slightly higher. In single-family houses, where hot water is billed on the basis of an invoice for gas for its heating, consumption may be lower. Data used as DHW consumption indicators for energy assessments of buildings should be updated, because this parameter continues to decrease, as can be seen in Table 1.

By determining DHW consumption based on the proposed method (Figure 1), the obtained water consumption values were significantly lower than those used for the energy assessments of buildings in Poland [25,26]:

- This indicator was  $0.85 \pm 0.005 \text{ dm}^3/\text{m}^2/\text{day}$  and  $27.4 \pm 1.4 \text{ dm}^3/\text{person}/\text{day}$  and similar to one obtained in Spain ( $25.7 \text{ dm}^3/\text{m}^2/\text{day}$ ) [16].
- The determined values were 39% lower than those used for the current energy assessments and 21% lower than those used in 2008–2014 [25].
- The value in terms of area was also lower than those found in Estonia [5] and using current methodology for energy assessments of buildings in Poland [26] by about 40%.

Domestic hot water consumption is affected, especially in residential buildings, by: technological solutions and distribution system [7,15], ability to control users [15], location (climate) [7–9], socio-economic factors (including building equipment) [7,38] and quantity and times of water intake [38]. User behavior can also be of importance [15,16,32,38]. Users' behavior in the case of DHW analysis is often defined as: time spent at home and at work [15,32], duration of sleep [32], usage of different household appliances [15]. People's behavior should be taken into account first of all for the preparation of consumption schedules and control of the technical system for the preparation of DHW to increase its efficiency [15] and for heat management on a building scale [38]. Users' profiles can also be included in applications that give people tips and recommendations to save energy [16]. As the research aimed to determine the average annual indicators to calculate the energy performance of buildings, the detailed behavior of users was not significant. In this paper, three independent single-family houses were investigated. Although, as it was mentioned, it is obvious that users' behavior influences DHW consumption, the obtained (measured) results of DHW consumption are very similar ( $\pm 5\%$ ). This may be a coincidence, but it may also mean that although the behavior of building users may be very diverse, averaged over one year/season is similar for different users, because the needs, and thus, also, the behavior of a given group of people living in the single-family houses are similar to each other. The situation would definitely change if a single-family house was inhabited by a couple without children or a single person, as was analyzed in [15]. Similarly, it is easy to imagine that a couple with two children will use a different amount of hot water than four adults, which is due to the dynamics of family life with children. For this reason, in our opinion, it should not be assumed that the average consumption of DHW is always similar. In order to obtain realistic data, further research is needed on different groups of people in different countries and climatic zones, which will enrich the database and draw more universal conclusions, e.g., on how the nature of the use of the building by its inhabitants should be taken into account in the calculations of the building's energy performance and when deciding on the choice of heating, ventilation and hot water systems considered as a whole—the technical equipment of the building. We believe that the measurement and calculation methodology presented in this paper will be used to achieve this goal.

It is debated whether to use indicators per surface area of the building [5,26], per capita [16,25,38], per apartment [38] or per bedroom (USA) [7] to make energy assessments of buildings. Determining indicators related to the area of the building is often introduced in such methodologies to calculate energy performance because it is easier to compare buildings (especially new ones) using this type of parameter when it is unknown how many inhabitants will ultimately be there. However, it is people who consume water, not the surface area, so it is equally reasonable to perform calculations for defining such indicators on a per-person basis, which was also noted in [7].

The analyses conducted herein showed that 30% of water consumption in buildings B1–B3 was the consumption of hot water. This indicator was slightly lower than that reported in the Estonian study [5]. The investigated buildings were equipped with similar water-using devices. The obtained range of domestic hot water consumption was 25–35%, which classifies these results in the upper range of values reported in the literature [27,28].

When using the DHW consumption index from the current methodology to calculate the energy performance of buildings in Poland [26], the PE requirement was not met. However, when the indicators for real buildings were used, lower values were obtained. Using the index from this methodology suggested that external partitions with lower heat transfer coefficients should be designed, although this is not necessary. Real indicators bet-

ter reflected the operational situation and did not expose investors to additional costs. It is therefore worth considering an assessment of the actual hot water consumption in existing buildings to demonstrate that the actual water consumption is lower, and furthermore, that this lower indicator should be used for the energy assessment of buildings.

Depending on the adopted DHW consumption index, the share of the total primary energy demand used for domestic hot water ranged from 36% to 48%, with the lower values corresponding to indicators determined in real buildings. According to the literature [27,28], the domestic hot water demand accounts for about 20% of a building's demand; the result obtained in this study was almost twice as high.

The analysis presented herein included three real buildings, the owners of which wanted to cooperate by taking readings and measurements. This research should be repeated for a larger group of buildings of different types. However, the analyses mainly aimed to show the effects of adopting DHW consumption rates that were too high, thus indicating that the real consumption of domestic hot water may be lower than that assumed in the certifications of residential buildings. These analyses were limited to buildings where only natural gas was used for heating and domestic hot water. The method of determining the DHW consumption based on the amount of gas consumed was approximate but precise enough to provide reasonable conclusions.

The relevance of the results to the wider population is unknown. Nevertheless, it should be noted that the research was carried out for independent single-family houses and in each of them, significant differences were observed between the actual and calculated domestic hot water consumption. The revealed differences are so significant that they should become the reason to initiate further research in this area, carried out on a larger number of buildings, not only in Poland, but also in the European Union and around the world, where the energy performance of buildings is calculated on the basis of pre-imposed indicators of specific consumption of domestic hot water.

## 5. Conclusions

The analyses conducted in this study can be summarized with the following conclusions:

- (1) The domestic hot water consumption indicators used in building certifications are too high. In single-family buildings, DHW consumption is 40% lower than that assumed in energy certification calculations.
- (2) Using a water consumption indicator that is too high often leads to PE values exceeding the required limit by up to 13%.
- (3) The designated domestic hot water consumption index for a residential building was determined to  $0.85 \pm 0.01 \text{ dm}^3/\text{m}^2/\text{day}$  or  $27.4 \pm 1.4 \text{ dm}^3/\text{person}/\text{day}$ .
- (4) This research involved a small dataset, so it should be repeated for more buildings and different types of building as well.

Therefore, it seems justified to constantly monitor the consumption of cold and hot water, and to analyze the impact of domestic hot water preparation on annual energy consumption. If similar conclusions can be drawn based on analyses from different countries and many real buildings, the possibility of introducing legislative changes to correct the DHW consumption rates should be considered in calculation methodologies for energy certification purposes.

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