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Review

A Review on Domestic Hot Water Consumption in Social Housing

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Abstract: Studying the resource consumption of a social housing community is very important due to the large-scale aspect of such programs and interventions. Despite the importance of domestic hot water consumption in social housing communities, it has never been specifically reviewed. This paper presents a comprehensive literature review on that topic to serve as a reference for future studies and projects. The topic was found to be approached differently across the world due to climate, cultural, and construction particularities. A great effort to associate solar-based hot water solutions with social housing was also found, particularly in places of high solar irradiance. Quantitative case studies were analyzed and compared, showing that domestic hot water consumption varies within every study, but not as much when comparing averages from different studies. Regarding factors that influence domestic hot water consumption, user behavior clearly plays a significant role, especially concerning the lack of information to the users on the available hot water system and its operation. Finally, the DHWC profiles and patterns available in the literature present similarities such as peaks in the mornings and evenings, and seasonal variations with less use in warmer periods.

Keywords: domestic hot water consumption; social housing; user behavior

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1. Introduction

Reducing hot water consumption represents an opportunity to increase water and energy efficiency simultaneously, contributing to achieving sustainable development goals [1]. The use of hot water represents a significant part of energy consumption in different types of buildings [2]. Regarding socio-economic aspects, there is a social gradient in which privileged communities see water as cheap and available, while underprivileged ones struggle to meet both health and welfare water needs [3]. Social housing residents tend to spend long periods at home, consuming more energy, which, consequently, raises their cost of living [4]. Water and energy poverty cause the lack of domestic hot water (DHW), which affects fundamental hygiene and sanitation needs, therefore resulting in poor families living under undignifying conditions [5].

Governments play an essential role in facilitating access to an adequate water-heating system that is compatible with people's needs and geographical location [6]. This role is even more important in the context of social housing, as governing authorities can help to significantly reduce carbon emissions [4] due to the scalability potential of the implementation sites [7] and nationwide programs. Energy policies that support efficient water-heating systems depend on the appropriate modeling of such systems [8] and the appropriate modeling depends on local and recent metering data since it is a geo-dependent variable [9]. Studies on the drivers of hot water consumption or with quantitative data on the subject are scarcer when compared to research on total water consumption and water end uses [1]. Although several studies have explored domestic hot water consumption across the world [2], few have carried out studies on social housing interventions. The present work reviews relevant monitoring studies in the social housing context in different parts of the world.

Nguyen and Teller [10] also highlight the importance of local studies to better understand the factors influencing water consumption in different contexts. Socio-economic factors, for instance, strongly influence the average daily domestic hot water consumption (DHWC), but there is limited information on how they affect the daily domestic hot water profile [2]. The evaluation of how DHWC in social housing is described in the literature, considering social matters and the particularities of this building typology, is the knowledge gap this study tries to fill.

The main contribution of this work is the comprehensive mapping of research conducted in social housing, summarizing the results related to temperature, usual technologies and hot water consumption in this building typology. To the best of the authors' knowledge, this is the first review article to focus on DHWC in social housing communities. For the sake of clarity, the term social housing will be used to describe any type of housing that targets low-income residents and provides private or governmental subsidies for rental or ownership. This work's main goal is to determine how much DHW a social housing resident consumes. Regarding DHWC in social housing, this study also analyzes hot water temperature, the influencing factors, the consumption profile, and the main water-heating technologies, while observing the differences and similarities found worldwide. Therefore, this review aims to summarize how domestic hot water consumption in social housing is addressed in the literature, providing a comprehensive overview of the research and recent developments in the field.

2. Materials and Methods

The importance of a proper query composition and a reliable database cannot be overstated, which led to the choice of Web of Science and Scopus as databases to retrieve scientific studies for the review. Web of Science and Scopus are the two world-leading citation databases, and both encompass a wide variety of high-quality studies [11]. A first look at the topic of interest made it clear that there were more energy-related studies than hot water ones. However, there were some important pieces of literature that combined the words "water" and "energy" to refer to the topic of hot water consumption in social housing. Also, different countries have different housing-related approaches, so a wide range of terms was employed to ensure global coverage of the topic. Therefore, the search string ("hot water" OR "water-heating*" OR "water heating" OR "water heater*" OR ("water" and "energy")) AND ("social housing" OR "low-income housing" OR "subsidized housing" OR "public housing" OR "workforce housing" OR "community housing" OR "affordable housing") was employed to find studies related to hot water consumption in social housing communities or in similar contexts. The string was composed to encompass as many relevant studies on this field as possible, using Boolean operators to optimize the search coverage.

Queries made in Web of Science were the same as those made in Scopus regarding the string search, however, the field codes available in each database are slightly different. In Web of Science, the search was refined by selecting only articles, reviews, and proceedings. In Scopus, the filters applied to the query were that the document could be an article, review, or conference paper. Because Scopus returned articles related to health and other similar topics, only papers in the engineering, environmental science or energy fields were considered. Although only articles in English were considered in both databases, two articles in other languages were found and removed. The timeframe included any articles published before 31 December 2021. More articles were found in Scopus than in Web of Science, which may be because Web of Science covers fewer journals than Scopus in the Natural Sciences and Engineering field, and due to the larger number of exclusive journals that Scopus covers compared to Web of Science in this field [12].

Skimming and scanning techniques were used to validate if each study comprised domestic hot water consumption in social housing. Context was always checked, since those terms may be used slightly differently worldwide, and only studies that encompassed housing for low-income groups were kept. Both private and public social housing projects were considered. The papers were, then, classified as "included" or "not included", with keywords tagging the inclusion reason and organizing the categories, as shown in the Supplementary Data. Studies lacking any original conclusions regarding domestic hot water were categorized as "off the subject" and disregarded. Studies without the social housing or low-income context or those which did not separate social housing from other dwellings were not included in the final analysis. Articles in which the conclusions on the volume of hot water demanded in domestic consumption could not be distinguished or isolated from that used for ambient heating were disregarded and considered "off the subject". Focusing only on hot water for ambient heating was also an exclusion criterion.

Studies that presented original conclusions on DHW in social housing were selected, since they may provide support and explanations to case study conclusions. More specifically, case studies monitoring DHW consumption and/or DHW temperature were the focus of the search. Figure 1 illustrates the search and selection methodology, with numbers referring to the number of articles in each step.

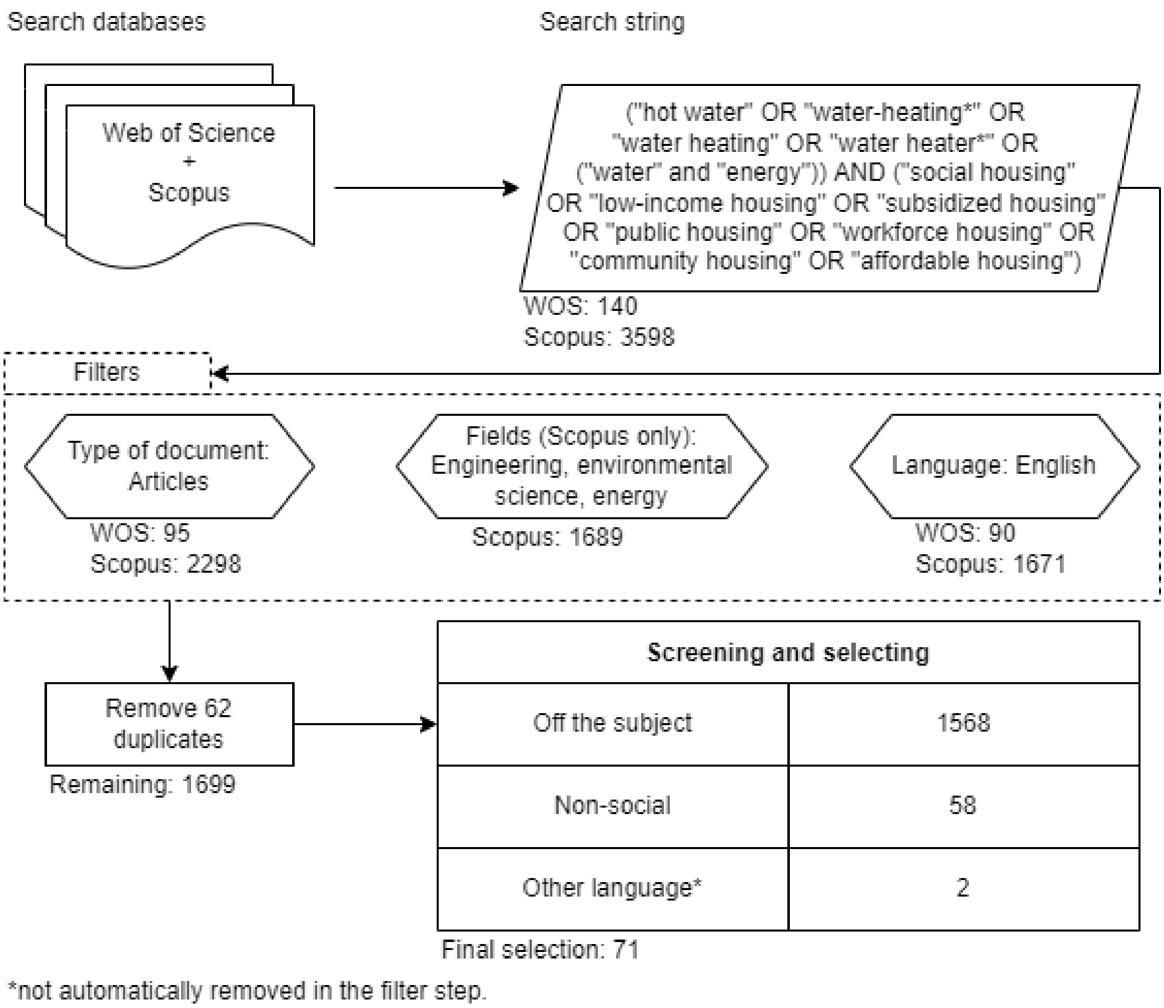

Figure 1. Flowchart of the search and selection methodology.

3. Results and Discussion

This section presents a brief characterization of the 71 selected studies, observing location and year of publication. Figure 2 illustrates the number of studies in each analyzed location. Some similarities can be observed with the results of McCabe et al. [7] regarding the origin of publications in their systematic review on applying renewable energy to social housing. In their work, the UK also had the highest number of publications on this topic. One important observation to make is that, considering the definitions of the United

Nations [13], all countries with studies on DHWC in social housing are either a developed (63 studies, 75% of the total of 84 countries studied) or a developing economy (21 studies, 25% of the total of countries studied). Hence, none of the world's most deprived areas were studied in terms of DHWC in social housing. In all social-housing-based studies in Latin America, showering was the only end-use considered. Figure 3 shows the per-country distribution of studies during the years, considering the country of the main author's institution for articles that involved more than one country. The number of publications has increased in the last decade.

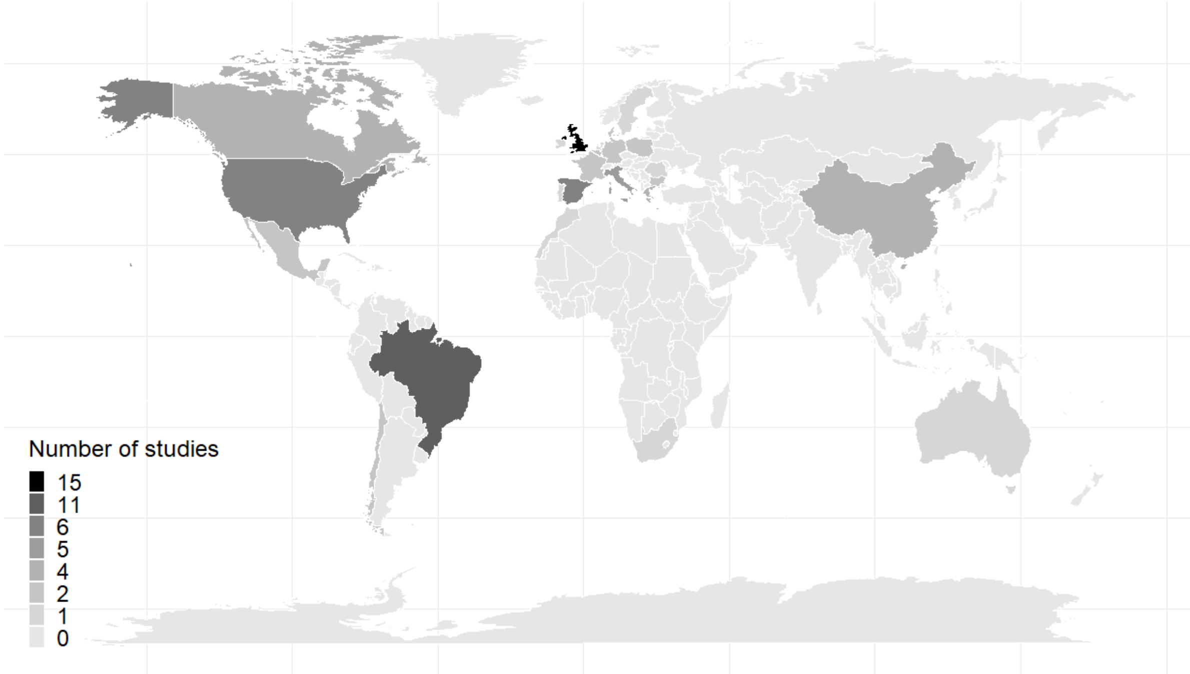

Figure 2. Number of studies focused on DHWC in social housing per location.

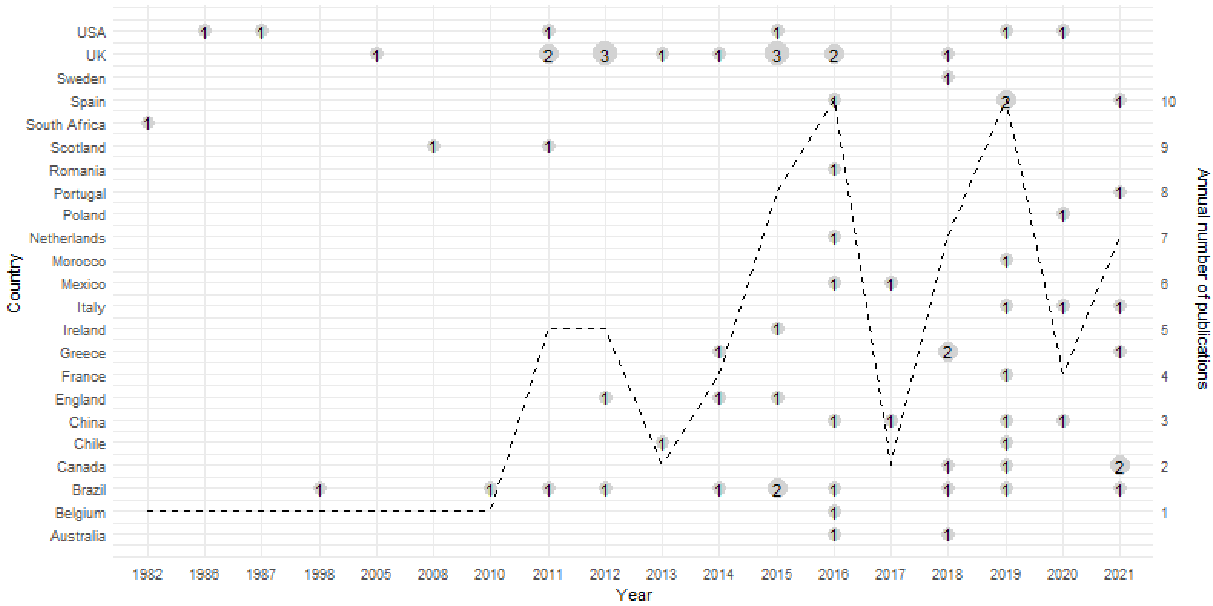

Figure 3. Distribution of studies on DHWC in social housing per country over the years (points) and total number of publications per year (dashed line). The numbers 1, 2 and 3 indicate how many pub-lications each country has per year.

3.1. Quantifications of DHWC and Measurements of DHW Temperature

This section is dedicated to core studies for this review article because they present data related to the quantification of DHWC and to DHW temperature. This section presents, respectively, DHWC per household, DHWC per person and DHW temperature. All measurements bring information on where and when the case study occurred, and what the water-heating system was. The water fixtures involved in the DHW system are specified when they were clearly mentioned in the analyzed study.

3.1.1. DHWC per Household

Table 1 presents information on DHWC per household in different studies. The references' years indicate the presence of studies in the 1980s and in recent years, with a 30-year gap. Regardless of the time gap, the most recent study and the oldest study present very similar DHWC averages.

Basson [14] explored the operation of a pipe-type integral solar water heater (SWH) made for low-income dwellings in South Africa. Based on a survey made with a few low-income dwellings in the winter rainfall area of the country, the mean volume of hot water consumed for both dwelling ownership modes (economic-rental and home ownership) was 140 L/household/day. The economic-rental dwellings used push-through geysers as the hot water system, while home-owned dwellings used combination geysers. The consumption was lower than in mid-income dwellings, in which DHWC varied from 200 L/household/day to 300 L/household/day [14].

Vine et al. [15] found that the DHWC in four multi-family social housing buildings in San Francisco, California, was 74 gallons (280.12 L) per household per day. In that study, DHW was available in the shower, bathtub, sink, washing machine and dishwasher. The value was slightly higher than what the literature at the time reported for single-family homes (65 to 70 gal/household/day, or 246.05 to 264.98 L/household/day). The authors stated that there was leakage in the building and that the housing authority used to pay for the DHW gas consumption, which might explain the increased DHWC. The authors [15] also defended that a master meter gives no economic incentive to save water and that the DHWC can be idiosyncratic. A 2.5 gal/min flow was considered for modeling, which was proven very close to reality.

Table 1. DHWC data from monitoring studies in social housing.

Data Source		DHWC per Dwelling	Water-Heating System	Reference
Building description and location	Time constraint			
Low-income dwellings in the winter rainfall area of South Africa	Not detailed	Average: 140 L/household/day	Push-through geyser; combination geyser.	Basson (1982) [14]
Holly Courts in San Francisco, California. Multi-family buildings with 18 units, California's first public housing project owned by San Francisco Public Housing Authority.	21 March to 22 August 1985.	Average: 74 gallons/household/day (or 280.12 L/household/day)	One solar-assisted (pre-heat) gas heater system per building.	Vine et al. (1987) [15]
High-performance multi-residential social housing building, with 40 apartments in Quebec City, Canada	1 January 2016 to 1 January 2017	Average: 131.2 L/household/day Standard deviation: 95.2 L/household/day	District heating, energy source not specified.	Rouleau et al. (2019) [16]
Four 4-story multi-family buildings comprising a total of 254 apartments and 2 commercial premises, Poland	1 January 2019 to 31 December 2019	8758.4 m^3/year for 254 dwellings (or 94.47 L/household/day, considering 365 days a year—daily resolution not available)	Local gas boilers (without condensation) houses	Bartnicki and Nowak (2020) [17]
High-performance multi-residential social housing building, with 40 apartments in Quebec City, Canada	October 2015 to August 2018	Average: 5.15 L/apartment/hour	District heating, energy source not specified.	Maltais and Gosselin (2021) [18]
	Control: March 2019 to February 2020 COVID-19 pandemic: 25 March 2020 to 25 July 2020	Average before COVID-19 pandemic (control): 152.6 L/household/day	District heating, energy source not specified.	Rouleau and Gosselin (2021) [19]

Bartinicki and Nowak [17] investigated a housing community's gas consumption, and since gas was used both to heat water and rooms, hot water consumption was also measured. In 2019, the total hot water consumption to amounted 7758.40 m^3, based on the readings of the residential water meters. Therefore, considering that there were 254 apartments, the average DHWC was approximately 94.47 L/household/day [17].

Rouleau et al. [16] used data obtained from 40 residential units in Quebec, Canada. The DHWC was 131.2 L/apartment/day, with a high standard deviation of 95.2 L/apartment/day. The DHW fixtures were shower, bathtub, sink, washing machine and dishwasher. Through linear regression analysis, the household size was found to influence the monitored data with a slope of 55 L per person, which is higher than that found in other non-socially focused papers. Authors believe this might be significantly related to the presence of children [16].

Maltais and Gosselin [18] studied the same multi-family building in Quebec as Rouleau et al. [16] and proposed a predictability analysis using neural networks. They provided a complementary description of the water-heating system, which consists of a centralized DHW system with an 1800 L storage at 60 °C. The system also uses a recirculation loop, which reduces the time required to obtain hot water at the terminal devices. Flow-meter-equipped heat meters were used to measure the DHWC at the water inlet of each dwelling from October 2015 to August 2018. Measurements comprised the same water end-uses as in Rouleau et al. [16].

Rouleau and Gosselin [19] analyzed energy consumption and DHWC during the COVID-19 pandemic in the same building as [16,18]. Data were collected from October 2015, and the authors considered four months of the pandemic period in the analysis: from 25 March 2020 to 25 July 2020. A control period was needed for the sake of comparison, for which authors used the data from March 2019 to February 2020. DHWC during the control period was, on average, 152.6 L/dwelling/day, which is higher than findings for the same building before the COVID-19 pandemic [18,19]. Compared to the control period, an increase of 17.2% was observed in April 2020, followed by reductions of 1.1% (150.9 L), 5% (145.0 L) and 24.3% (115.5 L) in May, June, and July, respectively. As the authors highlighted, such was not unprecedented, as consumption varied monthly in the control period from 114.2 to 180.2 L per dwelling per day.

3.1.2. DHWC per Person

Table 2 shows the DHWC per person, which varies significantly across the studies. The study that presents the lowest variability [20], did not measure the DHWC directly but rather estimated it from the energy measurements. The highest DHWC was found by Sodagar and Starkey [21], however, it was not directly measured either, but based on estimations.

Table 2. DHWC per person from monitoring studies in social housing.

Data Source		**DHWC Per Person**	**Water-Heating System**	**Reference**
Building Description and Location	**Time Constraint**			
Aspiring low energy/carbon affordable housing development, 25 houses in southern UK.	4 June to 17 August 2009	Minimum: 19 L/person/day Maximum: 47.1 L/person/day	Biomass and natural gas fueled district heating network	Gill et al. (2011) [22]
Four social houses certified to level 5 of the Code for Sustainable homes Standard in Gainsborough, UK	1 January to 31 December 2013	Minimum: 100.8 L/person/day Maximum: 225.8 L/person/day (measurements for mixed hot water ready for use)	Gas boiler	Sodagar and Starkey (2016) [21]
High-performance multi-residential social housing building, with 40 apartments in Quebec City, Canada	1 January 2016 to 1 January 2017, except from July to September.	Average: 58.3 L/person/day	District heating, energy source not specified	Rouleau et al. (2018) [23]
Large social intervention, 323 flats plus common areas and commercial spaces, in Italy.	15 October 2016 to 14 October 2018.	Average: 83.8 L/person/day Median: 63 L/person/day	Centralized water-to-water heat pumps (dedicated to heating, cooling and DHW)	Filippi and Sirombo (2019) [24]
Ninety-three homes located in France	1 January 2017 to 30 June 2018	Minimum: 56.7 L/person/day (η = 100%) Maximum: 58.8 L/person/day (η = 100%) Minimum: 51.0 L/person/day (η = 90%) Maximum: 53.0 L/person/day (η = 90%)	Electric heating	Csoknyai et al. (2019) [20]

Note: η = DHW system efficiency.

Gill et al. [22] investigated the water and energy performance of an aspiring low energy/carbon affordable housing site in the UK. Among other findings, the DHWC ranged from 19.0 to 47.1 L/person/day. Only the amount of heated water, known as untempered hot water, was measured, which represented from 22% to 44% of the total volume of water used per person [22].

Sodagar and Starkey [21] indirectly measured the DHWC based on other resources and procedures. They directly measured gas, electricity, and water consumption for four social houses in Gainsborough, UK. Because hot water and ambient heating were not measured separately, they considered that the gas consumption from June to September was related to hot water only. For the rest of the year, hot water demand was estimated by multiplying the average daily gas consumption over the summer and the number of days in the month. Calculations from the UK Government's Standard Assessment Procedure for Energy Rating of Dwellings were used to make other refinements. Finally, since harvested rainwater substantially provided water for outdoor watering and flushing toilets, fresh water was mainly considered for hot water consumption. The DHWC varied from 100.8 to 225.8 L/person/day. Those values are significantly higher than findings from other studies, which may be due to the assumptions and the fact that the results account for mixed ready-to-use hot water. One of the houses presented a consumption of more than 148 L/person/day, which was found, in the interview phase, to be a consequence of the household's lifestyle [21].

A large social housing intervention located near Milan, Italy, composed of 323 apartments, was analyzed for 2 years, from 2016 to 2018 [24]. In total, 154 occupied apartments were considered, and the results showed that the DHWC was, on average, 83.8 L/person/day, and the median was 63 L/person/day. The authors mention that the water consumption pattern presented unexpected variations between dwellings due to the different habits of the residents, with maximum hot water consumption greater than 400 L/person/day during the study period. The total daily volume demand was, on average, 150.8 L/person/day, considering both cold and hot water. The proportion of DHW in the total water consumption was 57%, which is higher than what Gill et al. [22] observed for untempered hot water. Previously, Sirombo et al. [25] analyzed data from the same intervention. By that time, a partial analysis (Condominium C) revealed a DHWC of 54 L/person/day, which was significantly lower than that found two years later.

Csoknyai et al. [20] analyzed the energy consumption of 157 homes in France and Spain, and the French ones (92 dwellings) were social housing projects. The consumption of about 50 homes was analyzed in depth, the criteria for participation were having an available internet connection and heating and domestic hot water generation based on electricity. Most of the apartments (90%) had electric water heating in a tank (50–150 L) installed. The DHWC was studied separately, based on energy audits, online surveys and monitored energy consumption. To estimate the DHWC in L/person, Csoknyai et al. [20] considered two scenarios, with 100% and 90% of system efficiency, both assuming 15 °C for cold water and 50 °C for hot water temperature. As expected, higher consumptions were in the winter and lower ones in the summer; with the consumption in June being 53% of the consumption in January.

Large DHWC variability was observed in most of the articles that quantified it. The average DHWC per capita obtained from direct measurements was as high as 83.8 L/person/day [24] and as low as 54 L/person/day [25], both for tempered hot water. All these studies were in the Northern Hemisphere, and only the case study of Rouleau et al. [23] was not in Europe.

3.1.3. DHW Temperature

The association between DHW temperature and consumption is very important and relates to the use of water and energy. Table 3 presents hot water temperatures in several studies and in different stages of the water-heating process. Measurements were found from 1982 to 2020 in a variety of locations.

Table 3. Hot water temperature data from monitoring studies in social housing.

Building Description and Location	Time Constraint	DHW Temperature	Water-Heating System	Reference
Low-income dwellings in the winter rainfall area of South Africa	Not detailed	Maximum temperature: 63 °C Recommended temperature: 40 °C Minimum temperature: 7 °C	Solar water heating	Basson (1982) [14]
Holly Courts in San Francisco, California. Multi-family buildings with 18 units, California's first public housing project owned by San Francisco Public Housing Authority.	21 March to 22 August 1985	Boiler average delivery temperature: 58 °C	One solar-assisted (pre-heat) gas heater system per building.	Vine et al. (1987) [15]
124 social housing dwellings in Glasgow Housing Association, UK.	July 2006 to February 2007	Intervention group Median temperature (bath): 55 °C IQR tap water temperature (bath): 54–58 °C Control group Median temperature (bath): 58 °C IQR tap water temperature (bath): 55–62 °C	Not specified.	Kendrick et al. (2011) [26]
22 social housing estates (150 households) in Camden, London, UK	Baseline: April and May 2009 Follow-up: June and July 2009	Average temperature (baseline): 55.2 °C Maximum temperature (baseline): 81.4 °C Maximum temperature (follow-up): 78.5 °C		Edwards et al. (2011) [27]
10 similar small rural social housing bungalows in UK	1 March 2010 to 28 February 2011	Average daily averaged temperature *: 52 °C Minimum daily averaged temperature *: 44 °C Maximum daily averaged temperature *: 57 °C	Ground-source heat pump (electric supplemented if needed)	Stafford and Lilley (2012) [28]
5 low-income social housing single-story units in Londrina/PR, Brazil	1 July 2013 to 30 July 2013	Minimum temperature: 34.51 °C Maximum temperature: 43.25 °C	Solar water heating	Giglio and Lamberts (2016) [29]
	-	Monthly average hot water temperature: 40.0 °C Monthly minimum temperature: 38.1 °C Monthly maximum temperature: 42.9 °C	Solar water heating	Giglio et al. (2019) [30]
Two social buildings from the Sustainable Ålidhem project, Sweden	Not specified	Average HW supply temperature: ~50 °C	District heating	Lindbergh et al. (2018) [31]
Large social intervention, 323 flats plus common areas and commercial spaces in Northern Italy.	15 October 2016 to 14 October 2018.	Heat pump average delivery temperature: 48 °C	Centralized water-to-water heat pumps (dedicated to heating, cooling and DHW).	Filippi and Sirombo (2019) [24]
Public housing building located in Kowloon Hong Kong, 40 stories with residential units, 988 flats	Questionnaire survey results (no monitoring)	Mean low temperature: 37 °C Mean high limit of hot water delivering temperature: 40 °C	Gas heating	Yu et al. (2019) [32]
Four multi-family buildings, each one 4-story high, comprising a total of 254 apartments and 2 commercial premises	1 January 2019 to 31 December 2019	55 °C	Gas boilers without condensations	Bartnicki and Nowak (2020) [17]

* = estimated from plot.

Basson [14] observed the temperature of the water heated in early autumn on a cloudless day. Water hotter than 40 °C was available after 11:00, reaching its maximum temperature of 63 °C at 15:00. After the peak temperature, water starts to cool but, if there was no draw-off, the temperature was greater than 40 °C until the following morning. A typical single draw-off test proved that it would be possible to obtain a total volume of 265 L of hot water at 40 °C if water from the unit was mixed with cold water at 25 °C. In the winter, however, when cold water is assumed to be 15 °C, 135 L of water at 40 °C can be drawn off at 16:00. Tests of resistance to freezing proved that the proposed technology was feasible for South Africa [14].

The average hot water delivery temperature observed by Vine et al. [15] was 58 °C, ranging from 56 °C to 62 °C between the four analyzed buildings. There was no significant correlation between hot water consumption and hot water delivery temperature. Authors expected it, since only 43% of the total hot water use was sensitive to water temperature (bathing and showering), with the remaining usage being a function of appliance set-points (washing machines and dishwashers) [15].

Kendrick et al. [26] focused on the hot water scalding issue. The authors analyzed bath water temperature and evaluated the use, impacts and effectiveness of thermostatic mixing valves (TMVs) in reducing bath hot-tap-water temperature. A total of 124 families that had at least one child under 5 years of age and lived at a social housing organization in Glasgow, Scotland, participated in the study. A pragmatic parallel arm randomized controlled trial method was employed. Methodology details can be found in Kendrick et al. [33]. Follow-up measurements showed that intervention arm families presented significantly lower bath hot water temperatures (46 °C, after 12 months) compared to families in the control arm (55 °C, after 12 months). After the intervention, problems with TMV were reported by 15% of the intervention arm households. Kendrick et al. [26] also found that intervention arm households were significantly "more likely to be happy or very happy with their bath hot water temperature"; "less likely to report temperature as being too hot"; and "less likely to report checking the temperature of every bath".

Differences in user perception were evident in the study by Kendrick et al. [26]. For example, both people that were and were not satisfied with the bath's hot water temperature described it as very hot—although some that were dissatisfied simply described it as hot. While most of the dissatisfied households (10) reported that the temperature was hot or very hot, two reported that it was not hot enough. Nonetheless, secondary outcomes from the intervention arm showed that bath water was not hot enough for 36% of families [26].

The study of Edwards et al. [27] proved that the scalding risk can be reduced in social housing without increasing the risk of *Legionella*. According to the authors, boilers are typically set to heat water over 60 °C to kill this bacterium. This is, in fact, seen in the work of Stafford and Lilley [28]. Nonetheless, the higher the temperature, the shorter the time needed to burn a child's skin [27]. On the other hand, the lower the temperature, the greater the time needed to kill the *Leoginella* bacteria [27].

Stafford and Lilley [28] analyzed 10 similar ground-source heat pump systems installed in small rural social housing bungalows in the UK. The heat pumps were electrically supplemented if needed and provided both space and water heating. The system performed "relatively well" in the summer and "relatively poor" in the winter, and the supplementary system was used mostly to mitigate the risk from *Legionella* bacteria during a weekly pasteurization cycle at 60 °C. Researchers chose one of the 10 systems to be the main subject of the study and measured the temperature at the top of the DHW tank. Furthermore, they calculated the daily average temperature from a 10-min-interval data sample. Daily averages were presented graphically and herein approximated to the values shown in Table 3. The authors attributed the good efficiency and low electricity usage in the summer months to the relatively low set-point temperature. During the summer, the system is basically used for DHW heating, due to almost no need for space heating. Since this led to better performance, Stafford and Lilley [28] concluded that the systems performed "relatively well" for DHW. They also highlighted that the DHW set temperature was lower in the summer, leading to good efficiency and low electricity use.

Giglio and Lamberts [29] conducted their study with low-income families who lived in a social housing project in Londrina, Brazil. From the 1272 single-story units, all with a solar water-heating system, they based their analysis on a selection of five residences that represented groups with common characteristics, previously identified by Giglio et al. [34]. The technology of the solar heating system was the thermosiphon SWH, in which potable water is heated directly in a flat-plate collector; cold water is provided from the supply network and passes through a pressure reducer before going into the water-heating system. The electric showerhead is used as a backup, and there is no electrical resistance in the hot water tank. The backup is controlled by the user when needed and presents three temperature levels: cold (no backup), warm (2.8 kW) and hot (4.5 kW). The water-heating system, hydraulic systems, solar orientation and weather conditions are considered identical for all units. Giglio and Lamberts [29] observed the use of the electric showerhead backup system even when hot water was available in the solar tank. The usage of the backup system even when water was available at 43 °C or more varied from about 20% to 80% of the total shower time, depending on the dwelling.

The results found by Giglio et al. [30] in Londrina, Southern Brazil, show an average difference between cold water temperature and shower water temperature of 16.1 °C. Cold water temperature ranged from 18.5 °C to 28.1 °C and hot water temperature ranged from 38.1 °C to 42.9 °C. The difference between cold and hot water temperatures varied from 10.7 °C in January (summer) to 24.4 °C in July (winter), which is more than twice as much [30].

Since different countries were analyzed, temperature measurements were expected to show great variability, which was found to be true. The maximum hot water temperature was 63 °C [14]. After 2016, the studies show temperatures of 55 °C and below. While most monitoring articles did not mention scalding water temperatures, two studies based on the same 22 social housing units in Camden, London, specifically addressed this issue. Durand et al. [35] were especially concerned about the vulnerability of young children and the elderly to scalding tap water. Young children's skin is more sensitive to temperature, while elderly people usually present slower reactions and mobility, which puts them at a higher risk. Furthermore, the Material Deprivation Index was identified as a risk factor that increases the odds of scalding in children under 5 years of age in the UK [36]. Temperatures reached 81.4 °C, while the average was 57.7 °C (Ref. [27] as cited in Ref. [35]). Many residents adapted their routine to the scalding hot water temperatures, but one-quarter of them affirmed that the water was unpredictably or inconsistently hot [35]. One solution that was found effective by the authors was reducing tap water temperature with passive methods.

Edwards et al. [27] made an experiment for tap water temperature, in which the social housing's boilers would either run a thermostatically controlled sterilization program (intervention) or the standard control. While the intervention would heat water to 65 °C from midnight to 6:00 and to 50 °C from 6:00 to midnight, the standard control kept the water at a constant temperature of 65 °C. The average hot water temperature at all 150 houses was 55.2 °C. Houses subjected to the intervention showed an absolute reduction of dangerously hot water temperatures (>60 °C) of 33%. Only one house that went through the intervention had a temperature higher than 60 °C after turning on the water for 1 min, while, in the control group, it happened in 23 houses. After the intervention, the average hot water temperature was reduced by around 4 °C, and the interviews did not reveal any signs of unacceptance [27].

Vine et al. [15] stated that only bathing and showering uses are sensitive to water temperature, which, in their studies, account for 43% of the total DHWC. However, interviews by Durand et al. [35] show some evidence that sink tap water, for example, is also sensitive to temperature. Evidently, this is a matter of user behavior, which is known for strongly influencing hot water consumption.

3.2. Hot Water Consumption Patterns and Profiles

DHWC can change according to the time of the day, the day of the week, and the month of the year [15]. In a study conducted by Vine et al. [15], the weekday hot water consumption profile in social housing is more representative of dwellings that are occupied during the entire day. According to the authors, peaks near mealtimes indicate cooking and dishwashing with hot water, while scattered peaks during the day refer to doing the laundry.

Typically, an hourly analysis shows two main peaks, one in the morning and another one in the evening, most likely related to bathing and showering [15,16]. DHWC is low in the early hours, increasing in the morning until it reaches a nearly constant level that is maintained until the evening peak [16]. As Figure 4 shows, morning peaks tend to be smaller than evening peaks, although such a difference is less evident in the work of Vine et al. [15] (Figure 4a) than in the work of Rouleau et al. [16] (Figure 4b). Figure 4a also shows how morning peaks may shift on weekends. Gill et al. [22] found that the profile for total domestic water consumption (hot and cold) also has two daily peaks, one in the morning and another in the evening.

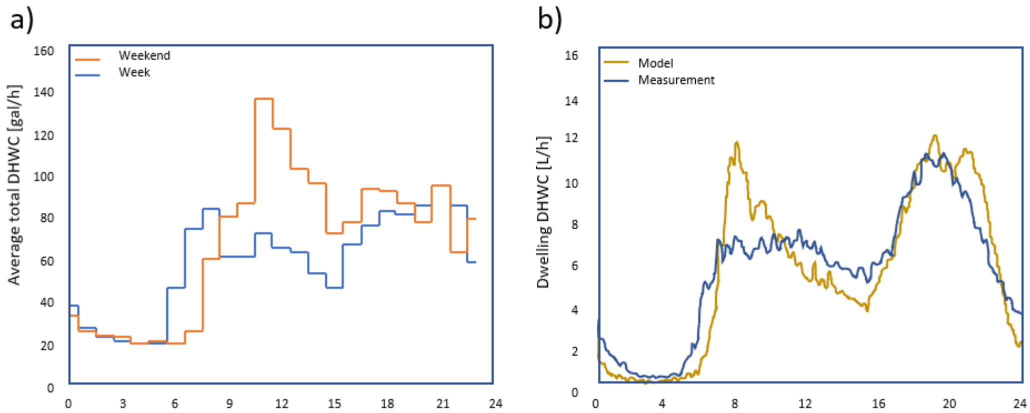

Figure 4. Hourly DHWC profiles adapted from (**a**) Vine et al. [15]. Reprinted/adapted from Ref. [15], Copyright 1987, with permission from Elsevier and (**b**) Rouleau et al. [16]. Reprinted/adapted from Ref. [16], Copyright 2019, with permission from Elsevier.

Working towards a prediction model with parameters locating the measurements in time (such as year, month, day, weekday, and hour), Maltais and Gosselin [18] found that the hour of the day, treated as continuously variable, was the only one highly correlated with the future demand. The correlation was positive, indicating that the later the time of the day, the more water is consumed, which the authors believe is because of the DHWC peak found in the evening when considering the consumption of the whole building. Maltais and Gosselin [18] added that there are units with DHWC profiles totally different from the building representative profile, as shown in Figure 5. Daily profiles allowed identifying boxes totally contained at zero, and 29 out of 40 units had null demand values for at least 75% of all daily time slots. Therefore, DHWC does not occur throughout the entire day, but mostly during specific dwelling-dependent periods. DHWC varied from one dwelling to another and from day to day [18]. Gill et al. [22] also found great dwelling-to-dwelling differences in total water consumption peaks in terms of size, duration and specific time.

Regarding the COVID-19 pandemic, Rouleau and Gosselin [19] compared the differences in consumption before and during the lockdown, as shown in Figure 6. DHWC was generally minimal at night, with two peaks, one in the morning and another in the evening. As Figure 6 shows, this changed mostly in the first two months of the lockdown, which indicates that occupants used their increased time at home to do hot water-intensive activities during the day. The authors observed an increase of 103% in DHWC in the middle of the day, from 9:00 to 17:00 during April 2020. June and July DHWC profiles look more like the typical DHWC profile seen in other studies, although with a reduced evening peak consumption. The DHWC peak shifted from 15:00 to 18:00 in June, and 19:00 in July, the latter was also the peak demand time during the control measurements [19].

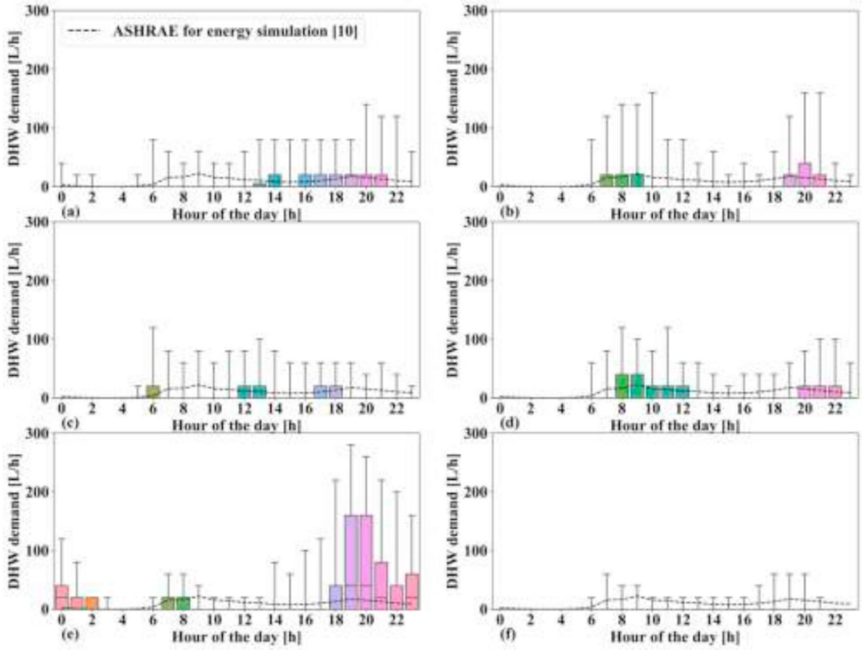

Figure 5. Average DHWC profile in 6 dwellings [18], being profiles from (**a**) a dwelling with consumption mainly during the evening, (**b**–**d**) dwellings with consumption in the morning and evening, (**e**) a high consumption dwelling and (**f**) a low consumption dwelling. Reprinted from Ref. [18], Copyright 2021, with permission from Elsevier.

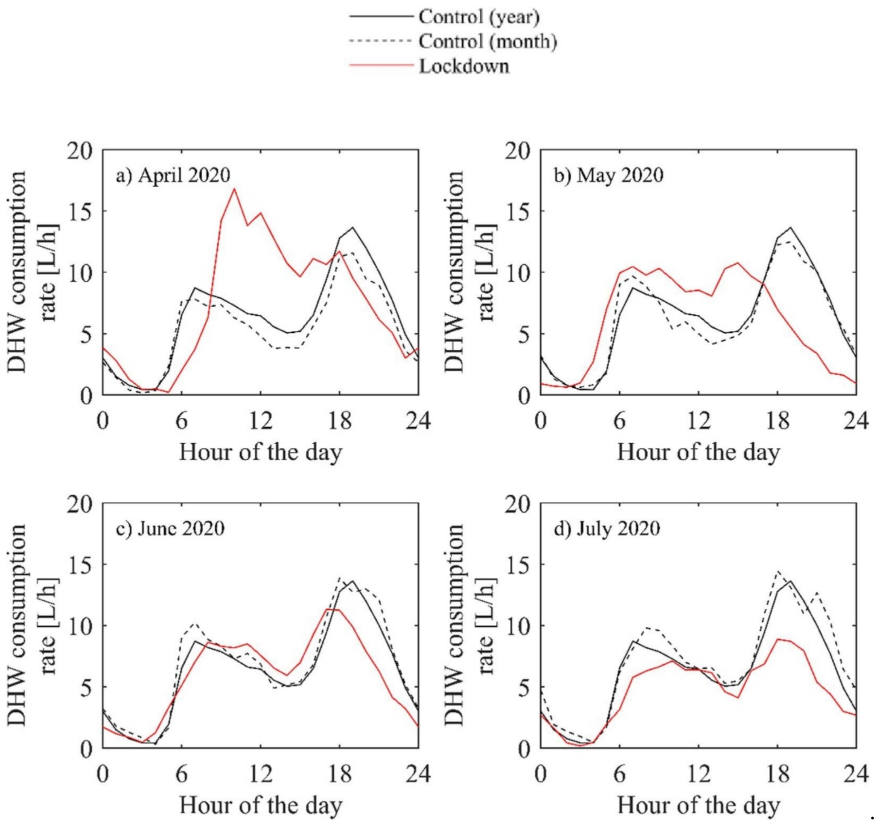

Figure 6. Changes in DHWC during COVID-19, average by month, being: (**a**) April 2020, (**b**) May 2020, (**c**) June 2020 and (**d**) July 2020. [19]. Reprinted from Ref. [19], Copyright 2021, with permission from Elsevier.

3.3. Factors Influencing DHWC

Hot water consumption, both in volume and temperature, seems to be most affected by user behavior. Some authors attributed the large variability of water and energy consumption [24] and of DHWC [15] to user behavior and preferences. The number of occupants, on the other hand, was seen as a weak predictor of DHWC in the case study conducted by Rouleau et al. [23].

Rouleau et al. [23] stated that occupant behavior significantly impacts DHWC due to different comfort specifications. In fact, later, when Rouleau et al. [16] adapted the DHWC model of Hendron et al. [37] and tested it in social housing data, the authors made changes to the model regarding occupancy, scale changes according to country differences, use of low-flow devices and dwelling-to-dwelling diversity. The latter accounts for the large variability found in non-social DHW monitored measurements [16].

Comfort specifications are not the only influence on user behavior. Giglio and Lamberts [29] observed that properly mixing hot and cold water to find the ideal temperature was challenging for users when it comes to SWH systems exclusively for shower use. They observed that, sometimes, even when water was available at 43 °C, the backup system was used, wasting energy. The authors believe this relates to the residents' lack of experience with water-mixing mechanisms. Similarly, some participants of research by Durand et al. [35] showed a lack of concern regarding their inability to regulate their domestic water temperature by themselves. One explanation is that users do not always understand how to manage hot water, as the interviews of Pretlove and Kade [38] made apparent.

Giglio and Lamberts [29] recommend training elderly people and low-education families on the operation and control of water-heating technology. As Leung et al. [39] explained, hot water needs for the elderly are different, since they present a declining heat storage capacity and therefore often become cold when bathing. Therefore, installing single-lever-type mixers can help provide a stable hot water supply and, consequently, improve the quality of life of the elderly living in public housing [39].

In Brazil, Ilha and Ribeiro [40] implemented an SWH system for showering and actively involved the community who benefited from the installation process. Residents were trained to build and install the SWH and attended environmental awareness and education workshops [40]. The authors considered that the success of their project is significantly connected to community acceptance. In a different scenario, when Hernandez-Roman et al. [41] evaluated a sustainable social housing program in Mexico, they found that 61% of the 194 households interviewed knew that they had SWH and 17% received training from the SWH system administrators. None of the users had had a solar water heater before (in their previous homes), and a physical inspection revealed that only 58% of households actually used the SWH systems.

During an air-source-to-water heat pump (ASWHP) trial in 18 households in England, Judson et al. [42] found that some users may have feared or resisted using the new technology as a reflection of their social and demographic profiles, as well as their position as tenants who have little power over the social housing they live at. In convergence with the findings of Ilha and Ribeiro [40], this resistance or fear may also be a consequence of the installation and instruction processes the users experienced [42]. The adaptation may have been easier because it mostly did not impact habits, although some users had trouble accepting that hot water was limited, and not supplied uninterruptedly, as is usually the case in the UK [42].

As the workshops promoted by Ilha and Ribeiro [40] also aimed at raising awareness, education probably played an important role in the acceptance of the technology. In fact, Giglio et al. [34] observed a direct relationship between the users' level of education and both the successful use of the technology and the mastering of the water mixing process for showering. Vine et al. [15] found education to be the only variable at a 0.01 significance level to influence DHWC, however, the authors believe that it can be explained by the relationship between education, income and appliances ownership.

Educating the user about hot water temperature is also effective, as shown in the study of Kendrick et al. [26]. The researchers employed TMVs installed by professional plumbers and used educational leaflets aiming at reducing bath hot water temperature. They concluded that the TMVs and educational leaflets are well accepted by families in disadvantaged communities and are effective in reducing bath hot water temperature both in the short and the long term, at least 12 months after the installation [26].

Some articles have explored how climate influences the DHWC. Giglio and Lamberts [29] found a strong correlation between air temperature and shower temperature in Londrina, Brazil, with no use of electricity for the backup SWH system from October to April. Maltais and Gosselin [18] did not find a correlation between DHWC and external temperature, which the authors attributed to hot water not being used for space heating. Burzynski et al. [43], on the other hand, reported a monthly DHW variability, with higher consumption in colder months and lower use in warmer months. Burzynski et al. [43], who analyzed more than 200 individual apartments in the UK, also concluded that the variation in DHWC is related to the size of flats and to the tenure, for both privately owned and social housing installations.

In Northern Ireland, 53 social housing tenants were interviewed regarding their perceptions of climate change, their behaviors and their willingness to reduce utility consumption in their homes in a study by Hayles and Dean [44]. Some energy-efficiency measurements are closely related to hot water savings, a couple of which are passive, and therefore could be implemented by social housing providers [44], while others depend on user behavior. The literature shows some examples of energy-efficiency initiatives that affect domestic hot water use, as follows: low-flow devices [45], heat recovery on drainage water [45], boiling only the water needed [46–48], using a lower setting for the water thermostat [46,47,49], washing clothes at a lower temperature [46,47].

In a study by Hayles and Dean [44], less than 20% of the participants had low-flow shower heads. The least accepted water-saving behavior was minimizing shower times and toilet flushing. The idea of installing low-flow devices led to 55% of the tenants being happy or very happy while the other 45% were either unhappy or unsure. Also, half of the interviewed tenants believed they could reduce their current water consumption [44]. The main motivation to participate in the study of Laskari et al. [50] on an energy and water-saving advice program for social housing and low-income households in Europe, reported by most (66%) dwellings, was the willingness to reduce utility costs [50].

Christidou et al. [51] investigated water and energy consumption in organized housing settlements in the Kastoria Region, in Greece. A total of 271 interviews were conducted, in which 94.5% of the households reported promptly fixing the taps when there are water leaks; 74.5% use the economy mode in dishwashers and washing machines, (74.2% use those machines only when they are filled up); and 67.9% take short showers. For saving devices, older respondents were significantly less likely to replace the shower, the kitchen and the bathroom taps with more efficient ones. The respondents with lower incomes were less likely to install economic showers. Nonetheless, 20 households already had economic showers, while 161 reported willingness to install one [51].

Brod et al. [52] analyzed two redeveloped housing sites in Boston, Massachusetts. At one of them, the Old Colony, built in 1941, there was a centralized steam boiler system providing heat for both space heating and DHW, which was inefficient since it was unable to separate those two demands. Old, high-flow fixtures such as faucets and showerheads increased the daily water and hot water consumption. After the redevelopment, both water and natural gas consumption decreased, which can be attributed to a couple of changes, such as the installation of low-flow fixtures, reductions in leaks and cracks in the pipes, and high-efficiency boilers with individual control per apartment and segregation of DHW and space heating demands [52].

Walker et al. [48] proposed retrofits in social housing in England. Besides updating the DHW system itself, there was a change from bathtubs (and some electric showers) to bathtubs with a mains-fed shower. There was resistance to using the new programming option that was implemented with the DHW system due to the habit (of manually setting the previously existing back boiler) and because the users felt in control of the hot water system. Comparing the pre- and post-intervention scenarios, bathtub use decreased (65% to 19%) and shower use increased (23% to 62%), and the main motivations were saving energy, saving time and increasing convenience. Some tenants found the new system more convenient, because it heated water faster, and increased their frequency of showers and/or baths. Nonetheless, some tenants kept having baths because they were more enjoyable [48].

3.4. Solar Water-Heating Technologies and Policies

When talking about hot water use in social housing, two main points should be considered: need and access [14]. When hot water is needed for low-income households, not only should the different technologies be considered, but also how accessible they are in terms of acquisition [14,53] and maintenance [54].

A study in Juazeiro, a city in the state of Bahia, Brazil, is a good example of a situation in which hot water is not used for both the lack of necessity (due to a warm climate) and access (electricity cost) [55]. The study explored a project to use more renewable energy to meet, among other energy-related needs, the water-heating demand of a social housing development. During a survey, 62% of the households reported not heating the water at all, and 26% heated shower water using an electrical showerhead. In addition, 12% of the households reported limiting the use of the water-heating system (an electric showerhead) due to energy cost, and 12% would consider installing one if electricity costs were lower [55].

Table 4 presents a summary of the different types of water-heating systems for social housing in the analyzed articles. Table 4 items were organized into the following categories: most used—for systems mentioned as the most used in that geographical area, for social housing, low-income families or in general; replaced—for systems that existed previously but were replaced by other technology; analyzed—for systems that were used in case studies; analyzed/proposed—a system that is being analyzed as a trial and also being proposed; and proposed—for systems that are being proposed by the author for social housing.

Table 4. Water-heating technologies mentioned in the literature.

Category	Hot Water System	Location of Analysis	Reference, Year
Most used	Gas	Australia	Urmee et al. (2012) [4]
	Gas	Santiago, Chile	Burgos et al. (2013) [56]
	Biomass and electricity installations	Spain	Ortega-Izquierdo et al. (2019) [57]
	Electric showerheads	Londrina, Brazil	Giglio and Lamberts (2016) [29]
	Electric or gas devices	Fez city, Morocco	Fertahi et al. (2019) [58]
	Gas	Hong Kong, China	Pan et al. (2016) [59]; Yu et al. (2019) [32]
	Gas	Perth, Australia	Esmaeilimoakher et al. (2016) [60]
	Electricity, firewood (includes biomass)	Romania	Şerban et al. (2016) [53]
	Electric water heaters	Hunan Province, China	Ge et al. (2020) [61]
	Electric showerhead	São Paulo, Brazil	Prado and Gonçalves (1998) [62]
	Tankless gas water heater	Netherlands	Filippidou et al. (2016) [63]
Replaced	Electric night storage heaters, gas ducted air and solid fuel/gas boilers (South Tyneside) Communal gas boiler	England	Judson et al. (2015) [42]
	Mains gas network, oil central heating or electric heating	UK	Caird et al. (2012) [64]
	Back boiler system with hot water tank	England	Walker et al. (2014) [48]

Table 4. *Cont.*

Category	Hot Water System	Location of Analysis	Reference, Year
Analyzed/Existing	Individual gas water heaters (separated from space heaters)	San Francisco, USA	Goldman et al. (1986) [65]
	Central boilers; individual forced hot water systems; group gas water heaters;		
	Individual gas water heaters		
	Central boilers; individual forced hot water systems; central gas water heaters		
	Central boilers; individual forced hot water systems; plant gas water heaters		
	Solar-assisted gas heater	San Francisco, USA	Vine et al. (1987) [15]
	District heating, not specified	Greece	Botsaris et al. (2021) [66]
	Biomass and natural gas fueled district heating network	Southern UK	Gill et al. (2011) [22]
	Solar thermal	Greenfield, USA	Perkins (2011) [67]
	Biomass district heating	London, UK	Ambrose (2014) [68]
	Gas-fired district heating	London, UK	Morgenstern et al. (2015) [69]
	Heat Pump	UK	Moore et al. (2015) [70]
	Solar-assisted heat pump fed by hybrid photovoltaic-thermal solar panels and seasonal storage	Zaragoza	Matínez-Gracia et al. (2021) [71]
	Solar thermal with electric showerhead backup	Londrina, Brazil	Giglio and Lamberts, (2016) [29]; Giglio et al. (2019) [30]
	Electricity-based system for hot water only	Spain	Karatasou et al. (2018) [72]
	District heating, not specified	Quebec City, Canada	Rouleau et al. (2018) [23]; Rouleau et al. (2019) [16]; Rouleau and Gosselin, (2021) [19]; Maltais and Gosselin (2021) [18]
	District heating, not specified	Sweden	Lindbergh et al. (2018) [31]
	Central space and water-heating system based on gas and district heating	Belgium, Bulgaria, Denmark, France, Germany, Greece, Italy, Poland, UK	Karatasou et al. (2018) [72]
	From main system (gas boiler)	Gainsborough, UK	Sodagar (2013) [73]; Sodagar and Starkey (2016) [21]
	From main system (gas boiler) + solar	Lincoln, UK	Sodagar (2013) [73]
	From main system (air source heat pump, radiators, electric)	Mews Lincoln, UK	Sodagar (2013) [73]
	From main system, complaint (air source heat pump, radiators, electric)	Grimsby, UK	Sodagar (2013) [73]
	Standard electric storage (0.92 EF)	Virginia, USA	Paige et al. (2019) [74]
	Solar thermal with electric showerhead as auxiliary	Florianópolis/SC, Brazil	Naspolini and Rüther (2011) [75]
	Centralized water-to-water heat pumps	Lombardy, Italy	Filippi and Sirombo (2019) [24]
	Gas boilers	Coastal region of Aveiro, Portugal	Oliveira et al. (2021) [76]
	Local gas boilers (without condensation) houses	Poland	Bartnicki and Nowak (2020) [17]
	Gas boilers	London	Edwards et al. (2011) [27]
	DHW storage tanks with electric heating	France	Csoknyai et al. (2019) [20]
Existing	Energy center and local piping network, with 1 hot water tank per building. Energy assets included solar thermal collectors, heat exchangers, heat exchangers, thermal energy storage tanks, biomass boilers, absorption chiller, economizer, cooling tower, 1 master geothermal heat pump, 1 slave geothermal heat pump and batteries	Greece	Botsaris et al. (2021) [66]
	District heating, with an individual instantaneous plate heat exchanger for DHW	Southeast London	Burzynski et al. (2012) [43]
	Centralized steam boiler	Boston, USA	Brod et al. (2020) [52]
	individual gas fuelled boilers	Torino, Italy	De Luca et al. (2020) [54]

Table 4. *Cont.*

Category	Hot Water System	Location of Analysis	Reference, Year
Analyzed/proposed	Solar thermal pre-heat with electric showerhead backup	Florianópolis, Brazil	Naspolini et al. (2010) [77]
	Photovoltaic/electric showerhead; hermos solar systems for heating bath water	Juazeiro, Brazil	Cunha et al. (2021) [55]
	Ground-source heat pump with electric cassette	UK	Stafford and Lilley (2012) [28]
	Solar water heater	South Africa	Basson (1982) [14]
	Photovoltaic/electrical	Greenfield, USA	Perkins (2011) [67]
	Integrated collector storage and hybrid PV/solar thermal	Greece	Souliotis et al. (2018) [78]
	Solar thermal	Fez city, Morocco	Fertahi et al. (2019) [58]
	Solar thermal	Tremembe, SP, Brazil	Moraes-Santos et al. (2015) [79]
	Solar thermal	Mexico City	Hernandez-Roman et al. (2017) [41]
	Heat pumps	Milan, Italy	Erba and Pagliano (2021) [45]
	Solar thermal and heat pump	Zaragoza, Spain	Martínez-Gracia et al. (2021) [71]
	Solar domestic hot water systems (thermosyphon and active forced circulation) and electrical showerhead	Florianópolis, Brazil	Cardemil et al. (2018) [80]
	Solar thermal	Romania	Şerban et al. (2016) [53]
	Low size solar thermal collectors coupled with low-temperature generator	Torino, Italy	De Luca et al. (2020) [54]
	A-rated combi-boilers with new heating system, including thermostat and radiator valves	England	Walker et al. (2014) [48]
	Solar water heater or air source heat pump	Zhejiang Province, China	Ge et al. (2020) [61]
	Heat pump	UK	Caird et al. (2012) [64]

The solar thermal water-heating system (SWH) is certainly the most frequently proposed DHW technology for social housing in the literature in the scope of the reviewed articles. SWH systems are frequently suggested because of the abundance of solar irradiance—for example, in South Africa [14], Morroco [58], Greece [78], Brazil [81]. Because of the solar water heating's intrinsic characteristic of being climate and daytime dependent, some solutions use it as assistance or pre-heating [15], while others use it as the main system, but install electric or gas-powered devices for backup [29] or boosting [4]. For Martínez-Gracia et al. [71], (i) hot water tanks can help reduce the lag between solar irradiation and DHWC, and (ii) solar energy storage and panel tilt, if well combined, can ensure that the demand is covered, avoid potential water overheating during the summer, and increase the solar contribution to DHW.

As a matter of fact, Basson [14] observed that most families used hot water in the latter part of the day or early evening. With the SHW, the water temperature was suitable for use only in the afternoon and early evening, with limited water during periods of bad weather [14]. This led to a lower acceptance of the SWH by families that could have an electric geyser and did not have to pay for electricity [14]. In a different scenario, in Brazil, Naspolini et al. [77] compared a group of households with a solar water-heating system complemented with an electrical showerhead with a reference group of 30 families that had all hot water requirements met with the electrical-only showerheads. Later, the low-cost SWH proposed in the work of Naspolini et al. [77] was implemented in different places across the country and is currently used in several social housing projects [29,75,81]. This combination of technologies is a solution to reduce electric energy demand peaks in the evening and provide savings for social housing residents [77].

By the time of Basson's [14] study in South Africa, solar water heaters were neither accepted nor had their use recognized by policymakers who were responsible for the choice of the water-heating systems. For Şerban et al. [53], even though there are grants given for the installation of an SWH system in Romania, they end up worsening social problems, since they are mainly used by high-income families [53]. This happens because, according to Şerban et al. [53], an SWH brings economic benefits at the usage phase, but it is not accessible for low-income families due to the higher initial cost when compared to conventional technologies.

In Brazil, Cardemil et al. [80] proposed a rebate program to assist low-income consumers to acquire an SWH system. Electricity utilities would cover the capital cost of the solar thermal system since they have a great interest in reducing on-peak consumption and can afford to rebate or directly subsidize the system [80]. The authors concluded that a relatively small subsidy can yield a significant reduction in on-peak consumption.

There is a program in Mexico that promotes SWH with revisions of norms and economic incentives for building industries and low-cost social housing developers [82]. In Mexico City, Hernandez-Roman et al. [41] evaluated the sustainable building program in social housing regarding the implementation of energy technologies to mitigate climate change. As reported by Hernandez-Roman et al. [41], CO_2 emissions in social housings in Mexico City could be reduced from 10.49 to 5.25 thousand tons by the year 2025 by changing the water heaters from LPG to hybrid (50% solar), while CO_2 emissions from electricity consumption for water pumping would be reduced from 0.17 to 0.08 thousand tons using shower water saving devices [41].

In Chile, according to López-Ochoa et al. [83], a solar DHW regulation subsidizes solar water-heating systems in newly constructed social housing targeted at vulnerable families. Also in Chile, Burgos et al. [56] analyzed how indoor air quality changed when relocating families from slums to public housing, and showed that using dirty fuel to heat bathing water was the second main concentration indicator of particulate matter with less than 2.5 microns in diameter (PM2.5), ranking higher than smoking more than three cigarettes indoors. The water-heating technologies used in slums were mainly (40.3%) electricity or nothing, but gas stoves (31.9%), open fire with wood, coal or waste (27.8%) were also used. In the analyzed public housings, gas was the main fuel, found in 81.0% of homes, while electric or none were present in 19.0% [56].

Gas is the most used source of energy for water heating in many countries, as shown in Table 4. In Perth, Australia, most homes analyzed by Esmaeilimoakher et al. [60] used gas water heaters, and a couple used electric water heaters. Also in Australia, a study by Urmee et al. [4] encompassing 3377 dwellings showed that the main water-heating systems were gas storage water heaters (28%) and gas instantaneous water heaters (15%). Solar water heaters represented 23% (16% electrically boosted and 7% gas boosted). Electric water-heating systems, considered inefficient by the authors, accounted for about 30% (24% electric storage heating and 6% electric instantaneous heating) [4].

Based on information from 757,614 dwellings of the Dutch non-profit housing, Filippidou et al. [63] concluded that high-efficiency condensing boilers replaced tankless gas heaters, gas boilers and "conventional" low-efficiency boilers from 2010 to 2013. A change for sustainable technologies such as Micro-Combined-Heat-and-Power-Plants and heat pumps were not observed. In fact, of dwellings with heat pumps in 2010, 20.4% were replaced with a condensing high-efficiency boiler by 2013, which authors attributed to the fact that heat pumps are slow to heat water if compared to boilers [63].

Caird et al. [64] analyzed 83 dwellings with heat pump systems in the UK, including both private and social housing units. The monitoring process and in-depth survey analyses allowed concluding that most users (90%) agreed that the system met their DHW requirements, and private householders expressed higher levels of satisfaction with their heat pump systems than social housing householders. Higher system efficiency was found to be associated with a better user understanding of how the heat pump system works and with more continuous operation, and they were significantly more frequent in private dwellings [64].

Ortega-Izquierdo et al. [57], based on 1250 interviews over the phone in Spain, found that user preference for water heating is related to the type of building, location, and income. Electrical installations and oil boilers were found to be more usual in low-income households, with the latter also being common in rural families. Natural gas was more used in urban and multi-family dwellings with higher incomes. Solar thermal energy was found to be typically chosen by men, aged over 60, living in urban areas in dwellings with more than four bedrooms with high occupancy and above-average income. On the other hand, biomass and geothermal water-heating systems were more frequent in rural areas with high incomes. This was found to be slightly related to education, in a way that people with a university degree chose the solar thermal systems and people with primary and secondary education would prefer biomass [57].

In some countries, social housing also involves a complex tenant–landlord relationship. For instance, Csoknyai et al. [20] observed that recruiting for the experiment with social lessors could lead to uninterested and edgy participants, possibly caused by the non-neutral and non-objective relation between social lessors and their tenants. Hernández and Phillips [84] used surveys and interviews with 20 households and their landlords to study the impacts of energy upgrades in low-income housing in New York City. One landlord mentioned that the replacement of an old and troublesome boiler resulted in an improved landlord–tenant relationship. In other cases, renovations led to problems: water leaks, delays for hot water to arrive at the shower, and the lack of hot water and heating [84].

Remote and automatic boiler control, which allows the landlord, not the tenant, to control the boiler, can also be a source of problems [84]. Nonetheless, in the UK, the tenants' inability to control and program the heat pump system made them overcautious and reliant on the landlord or neighbors to operate it [70]. In summary, the lack of information had tenants feel unconfident and less capable, which was also shown to be related to dissatisfaction [70].

Lovell et al. [85] observed that the experience of living in a better-quality house altered the preference of residents that would initially not care for sustainability in a house. One of the interviewed social-housing residents commented that he would be looking for a house with a solar water heater and a rainwater tank in case of moving to a new house [85].

Erba and Pagliano [45] suggested that city planning and building design could work better if integrated. The authors exemplified it with water-saving devices, also mentioned in studies regarding factors influencing DHWC as described in Section 3.3, or a comfortable shower instead of bathtubs. Cities could provide information on campaigns for water-saving devices, and the legislation and regulations would play their part through mandatory labeling of low-flow water devices, or making showers mandatory rather than or in addition to bathtubs [45]. Public policies can be planned to promote the adoption of sustainable water-heating technologies in social housing programs, considering climate aspects, in addition to cultural and economic factors [81].

3.5. Opportunities for Future Research

Whilst several articles were found presenting relevant information on DHWC in social housing, there is still an opportunity for future research. For instance, the main reason behind a large number of discarded articles was the decision to search for key terms in the entire article, not only in the abstract, title and keywords, because domestic hot water is not frequently the main subject, but rather a secondary one. Therefore, one could expect to find information gaps on the domestic hot water consumption in social housing.

A common gap in articles is information on hot water consumption and profile at the end-user level, although some articles describe such use and others analyze buildings where there is only one hot water end-use. This piece of information would be very helpful when comparing different locations since it would be a fairer comparison, as some places indicate the use of hot water only for showers in social housing buildings. In addition, many articles are not explicit about the type of measured hot water (tempered or untempered), which may lead to misunderstandings.

Many social housing buildings are equipped with communal water heating systems, but little is known about the impact of this choice over individual water systems in terms of user behavior and comfort. For instance, occupants may or may not have control over the temperature of the provided hot water, but either way they are responsible for mixing it with cold water to reach their comfort needs. Design for sustainable behavior could be further explored along with other sustainability initiatives that are already being studied.

Few articles reviewed mentioned a concern with the Legionnaires' disease. Although this could be caused by the process of selecting the articles, health should be a concern in engineering matters. Future research on DHWC, especially the ones that involve a temperature analysis, could provide measurements to reinforce that the heating system is not only comfortable and low-cost but also safe from *Legionella*.

Finally, even though there is a frequent concern about cost-saving during operation, there is no information on monitored implementation, operation and maintenance costs. This piece of information is particularly important in social housing in order to protect vulnerable communities from the lack of hot water and to guide governments, designers and constructors to invest wisely in the best technologies.

4. Conclusions

This paper reviewed domestic hot water consumption in social housing communities, showing that this research topic was studied in many places around the world, frequently as a secondary subject in articles on energy consumption. This article is now a reference for hot water consumption and temperatures in the social housing context. Sustainability was often mentioned as one of the motivations for many of the interviewees, and systems based on solar water heating and heat pumps were proposed by different authors.

One of the limitations of this research is that, by choice, it does not comprehend conclusions and analyses from an energy consumption perspective, since our goal was to obtain information on hot water consumption itself. Health and economic aspects were not studied in depth, which is another limitation of this paper, but an opportunity for future research. Social housing and sustainability are proven to work well together, but challenges are usually found mainly in terms of user behavior and experience. Future research on local domestic hot water consumption in social housing communities and its respective policies is necessary, particularly in less developed countries, to guide governments and share challenges and solutions with the scientific community. The relationship between age, hot water temperature and heating technologies could be further explored to determine best practices focused on the elderly and children in the social housing context. Moreover, the relationship between water and energy consumption (and related expenses) for families living in social housing, considering different water-heating technologies is another important topic to be explored in future research.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14172699/s1, We included a spreadsheet with data from all the articles found in the search. The spreadsheet contains the following information for each article found: author, title, year, source title, document type, source, classification (selected or duplicated), and reason to discard (in case the article was not included in the review).

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List of Abbreviations

DHW	Domestic Hot Water
DHWC	Domestic Hot Water Consumption
KPI	Key Performance Indicator
SWH	Solar Water Heater

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