HUNGARIAN AGRICULTURAL ENGINEERING
N° 36/2019 29-37
Published online: http://hae-journals.org/
HU ISSN 0864-7410 (Print) / HU ISSN 2415-9751(Online)
DOI: 10.17676/HAE.2019.36.29
Received: 2019.10. 05. - Accepted: 2019.12. 28.

PERIODICAL OF THE COMITTEE OF AGRICULTURAL AND BIOSYSTEM ENGINEERING OF
THE HUNGARIAN ACADEMY OF SCIENCES
and
SZENT ISTVÁN UNIVERSITY
Faculty of Mechanical Engineering

CONSUMPTION PROFILE BASED ANALYSIS OF SOLAR THERMAL SYSTEM FOR DHW IN BUILDINGS

Author(s):
Qudama AL-YASIRI[1,2] , Márta SZABÓ[1]

Affiliation:
[1]Department of Building Services and Environmental Engineering, Szent István University,
Páter K. u. 1., Gödöllő, H-2103, Hungary
[2]Department of Petroleum Engineering, Faculty of Engineering, University of Misan
Amarah City, Misan Province, 62001, Iraq

Email address:
szabo.marta@gek.szie.hu, qudamaalyasiri@uomisan.edu.iq

Abstract

Solar thermal system for domestic hot water (DHW) is one of the most common application for utilizing solar energy. Consumption profile of hot water has a significant impact on solar DHW sizing as it relates many uncertainties regarding human nature, which is difficult to predict therefore. The size of solar thermal system is roughly estimated in most cases which can results operational difficulties and efficiency losses. In this paper, different DHW consumption profiles have been analysed. The influential parameters on consumption, sizing methods and proposed modelling techniques for solar DHW are discussed and concluded with findings of several case studies.

Keywords

domestic hot water (DHW), consumption profile, solar thermal, solar thermal application in buildings

Introduction

Merging of renewable energy sources with energy consumption sectors among the hot topics attracted researcher's attention nowadays. Solar energy, in particular, is the fastest growing renewable energy industry in the last decades in both electrical and thermal directions [1]. According to the International Energy Agency IEA, building sector is the biggest consumer of thermal energy where it may accounts about 46% of total building energy and the share of renewable sources will be developed by 20% by 2023 in this sector (IEA, 2019). Thermal energy in buildings mainly delivered for space heating and hot water for domestic usage. DHW consumption has a relatively variable share of thermal energy in building sector in different countries as it depends on several physical, cultural and geographical considerations. The energy needed for DHW consumption share about 14% in Europe, 18.3% in USA, 22% in Canada, 25% in Australia, 27% in China, 29% in Mexico and 37% in South Africa [2], and ranging from 16-50% in most of developing countries [1].

Solar thermal systems for DHW

The shape and size of solar thermal system (STS) is different from a building to another depending on the total DHW consumption for end-use and building type. STS mainly consists of the same main components which their performance impact the performance of the whole solar system. These components are: solar collector, heat exchanger and storage tank in addition to the pumps and other measuring and control devices that complete the main loops of the system.

Solar collector

The main objective of solar collector (s) is (are) collecting the incident solar radiation and transfer the harvested heat to the heat transfer fluid (HTF), which the latter transfers the heat to a storage tank through the arrangements of heat exchanger. This HTF represent the blood of solar system's body and it has a specific physical and thermal properties effect the overall solar system performance significantly. The main two types of solar collectors used in DHW level are the flat plate collector (FPC) and evacuated tube collector (ETC). The FPC is the most common type used in solar thermal applications, especially for

DHW. All FPCS comprise from the following components: absorber layer, fluid network, insulation and the frame (box). Many improvements have been done to increase the efficiency of FPC by increasing the area of absorber, arranging the fluid network in zigzag manner other that the parallel, using of nano-fluids for better heat transfer etc.

The ETC is the better version of solar collectors in solar thermal systems. It comprises of a number of glass tubes mounting on a frame. Each tube has two concentric glass tubes having evacuated space between them. The HTF interring the inner tube and collects the incident solar radiation. The outer surface of inner tube is coated with absorbing material which transmitted through the outer tube. The evacuated space between the tubes play a vital role to minimize the conductive losses of solar radiation which make the collector efficient. Broadly, the performance of ETC is better than the FPC in solar thermal applications where a study- dealt with two solar thermal systems used FPC and ETC- showed that the annual solar fraction of ETC is higher than that of FPC by 16%. Moreover, the study reported that the energy generated by ETC is more than the energy of FPC by 9% which indicated more cost saving of ETC [3]. More technical and economic advantages of ETC are tabulated in Table 1.

Table 1. Comparison between FPC and ETC [4]

Criteria	FPC	ETC
Temperature range (^{o}C)	60 - 80	60 - 120
Heat generation	Slow	Quick
Efficiency at high temperature	Low	high
Emissivity	High	Low
System sizing at location of average availability of solar radiation	Required	Not required
Major maintenance requirement (Durability)	15 years or more	5 years or more

Heat exchanger

The heat exchanger is the other main part of STS which circulate the thermal energy between the collector/s and the storage tank. It usually made of materials that have excellent thermal conductivity and high corrosion resistance such as copper, Aluminium, stainless steel etc. the heat exchanger transfers heat either directly or indirectly where the direct method has more energy saving than the indirect arrangement. Furthermore, the indirect heat exchanger can be made with single or double row. The performance of single and double row heat exchangers with different lengths and cross- section area have investigated by [5-6]. Their study showed better thermal efficiency of single row heat exchanger and the initial and operational cost of STS were reduced.

Storage tank

The main objective of storage tank is storing the thermal energy harvested by the collectors and deliver it to the end-use application. The storage tank guarantees the continuous delivery of the hot water without intermittency. It represents the heart of STS where it significantly effects the design and size of solar system and as a result, the cost. The heat stores in the tank mainly in three methods: sensible, latent and thermo-chemical reaction. The method of storing depends highly on the amount of thermal energy to be stored and type of application (end-use). The main characteristics among the three type methods are tabulated in Table 2. The sensible method for storing water (as a storing medium) is the most popular and widely used method in hot water applications as it covers hot water demand in acceptable initial and operational cost. The mixing of cold and hot water is the main problem of sensible storage systems and the thermal stratification is highly recommended for this matter.

Solar fraction (the percentage of DHW consumption that covers by STS) is the most important factor that should take into account by designers to get the optimal STS with minimal cost. Some designing studies recommend the ratio of solar collector area (Ac) to the hot storage volume (V_S) to get the optimal sizing for STS, where the optimal solar fraction lies within the range ($0.05 \text{ m} \leq A_C/V_S \leq 0.18 \text{ m}$) [8].

The STS generally classified as active solar thermal systems (ASTS) and passive solar thermal systems (PSTS) where the latter has no pump(s) to force the working fluid for circulating. Moreover, ASTS also classified as direct and indirect ASTS where the working fluid flows directly or indirectly between the collector (s) and the storage tank, see Fig 1.

Table 2. Typical parameters of different storing methods [7]

TES System	Capacity (kWh/t)	Power (MW)	Efficiency (%)	Storage Period	Cost (€/kWh)
Sensible (hot water)	10–50	0.001 – 10.0	50–90	days/months	0.1–10
Phase-change material (PCM)	50–150	0.001 – 1.0	75–90	hours/months	10–50
Chemical reactions	120–250	0.01 – 1.0	75–100	hours/days	8–100

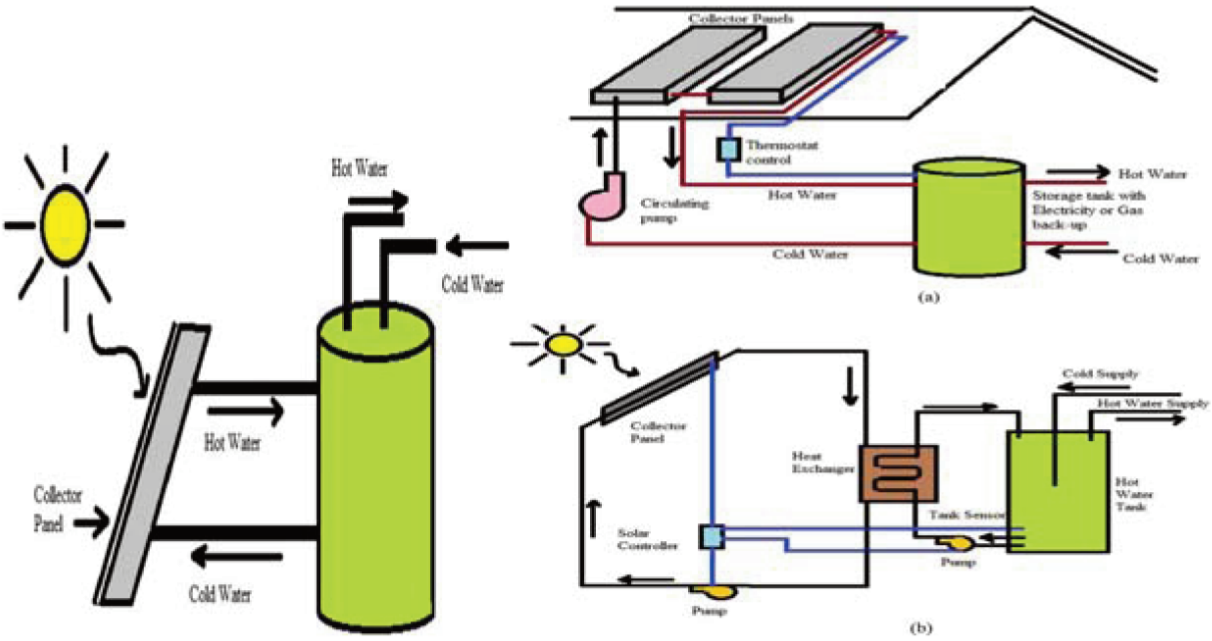

Figure 1. Schematic view of PSTS (left), (a) direct ASTS and, (b) indirect ASTS (right) [2]

DHW consumption profile in different buildings

The DHW consumption in buildings is usually linked to the daily activities of users/occupants such as hand-washing, showering, bathing, laundry, sink and dish-washing etc. The daily usage of DHW is fluctuated from time to time during the day depending mainly on the human activities and the pattern of use.

The DHW consumption profiles in buildings is different because we are dealing with a variable number of users, different peak periods and different activities. The consumption profile in residential buildings is variable from one activity to another where they mostly relevant to social, behavioural and lifestyle aspects. The peak consumption can be noted in the morning and evening with less consumption in the afternoon [9]. For the DHW consumption point of view, a study of Jordan & Vajen, 2001 [10] indicated that the extractions of DHW for a European household of 200 l/day at 45oC in Switzerland and Germany are separated as following: 80 l for shower, 20 l for bath, 28 l for sink and 72 l delivered for dish and cloth-washing. In the same direction, a recent study done by [11] summarized the range of DHW consumption profiles in residential buildings for several EU countries namely in Denmark, Netherlands, Austria, Germany, Sweden, Spain and Estonia. The study showed that the flow rates for bathroom sink, kitchen sink, shower and bathtub are ranged between 0.03 − 0.1 l/s, 0.08 − 0.2 l/s, 0.13 − 0.58l/s and 0.11/s − 0.3 l/s, respectively. Hendron, 2010 [12] reported that the average DHW consumptions in a household of 300 l/day consumption (cold & hot) in Network city, USA are 105 l for showering, 95 l for bath-sink, 57 l for laundry, 26 l for bath and,19 l for dish-washing. More consumption ranges can be seen in Table 3, regarding different EU countries, USA and Canada according to Annex 42 report based on average usage of 100-120 l/day at 45 oC for households of 100 m2. The duration and frequency of using the DHW is another effective factors in the consumption profiles in residential buildings. Most of DHW extractions are relevant to the use of shower and bath during activity period in the morning and evening, and the duration of 2-3 min. presents about 30% of the daily consumed DHW [13].

Table 3. Daily hot water and energy consumption for different countries [14]

Country	Daily DHW consumption per household (l/day)	Daily DHW consumption per occupant (l/occupant.day)	Daily DHW energy usage per household* kWh/day
Canada	236–303	94	12.3
USA	202–250	40	5.22
Switzerland	138	55 at a 50 °C rise	7.18
Finland	135	43	5.61
UK	102–117	20–39	3.85
Germany	160	64	8.36
France	1.74 per m^2 (at a 30 °C rise)	69.6	9.1
Spain	75	30 (at 60 °C)	3.92
Portugal	100 (at a 45 °C rise) (apartments)	40	5.23

In hotel buildings, the total energy consumed for DHW accounts to be ranged between 10- 40% [15]. The DHW consumptions in hotels are set to deliver optimal comfort levels to the guests where the main activities regarding the restaurant, kitchen, baths, gym, laundry, swimming pool etc. Many studies reported that the luxury hotels are consuming hot water more than the others compared to its size. Hamele and Eckard, 2006 [16] reported that the hot water consumption in the EU hotels is so high. Their study which done based on 191 hotels separated in different European countries has indicated that the average consumption is 231 l/guest. Another study done by Deng, 2003 [17] stated the about 40% of hot water share for laundry, 30% for guest usage and 22% shared by the kitchen. This study also indicated that most hotels tend to use external laundry services and that may share the DHW consumed for guest usage and kitchen extractions by about 44% and 55%, respectively.

The hospital buildings are characterized as a big consumer of DHW. Many activities regarding patient care, kitchen activities and cleaning services. Several studies reported the importance of the amount of hot water consumed by hospitals. A study showed that the average daily consumption of DHW in the European hospitals is ranged from 80-130 l/bed, while it is between 100-150 l/bed in USA [18]. Another study indicated that the DHW profile in the Norwegian hospitals are vary within the day and the peak load start at 8:00 and it gets constant later until evening period [19]. Moreover, the study stated that the energy delivered for heating the water account as 7.1 W/m2. Other details regarding DHW profiles for different buildings can be seen in Table 4 and Fig. 2.

Table 4. DHW consumption in different type of buildings.

Reference	Location	Type of building	Main findings/ Consumption load
(Agnieszka et.al, 2017)	Wroclaw, Poland	Multi-apartment building (626 apartment)	-Average daily DHW/ apartment, (m^3): 1 room (0.051), 2 rooms (0.074), 3 rooms (0.104) & 4 rooms (0.105).
(Dzintars et. al, 2015)	Riga, Latvia	Apartment buildings	- Energy consumption for DHW is 33 kWh /m^2 - Energy for DHW = DHW needs+ distribution losses
(Janusz B., 2010)	Bydgoszcz, Poland	Hospital (2-hospitals)	-The average DHW consumption during weekdays (Mon.-Fri.) was higher than weekend days. - The highest consumption between 8:00 and 19:00 while, the lowest between 1:00 and 6:00. - Daily DHW consumption 111-124 l/bed
(Ahmed K. et. al, 2016)	Helsinki, Finland	Dwellings (86 apartments & 191 occupants)	-Higher peak in evening hours (2-4 times higher than non-peak hours). -Morning peak hours (7:00 - 9:00) while, evening hours (20:00 t0 22:00) during weekdays. -Daily average DHW consumption are: 38.5, 47 and 45.2 l/person/day for the month of Aug., Nov and Jan., respectively. -In peak hours, the consumption varied from 0-107 l/person/day.
(Barbern R. et al., 2013)	Zaragoza, Spain	Hotel (4-star, 117 rooms & □190 beds)	-Water saving devices in taps in shower and other areas -Reduction by 33.2% in the total hot water consumption - Average daily DHW fallen from 321 to 252 l/guest (21.4%)
(Tortella B, & Tirado D., 2011)	Mallorca, Spain	Hotels (1-5 stars)	□541.6 l total water/guest day

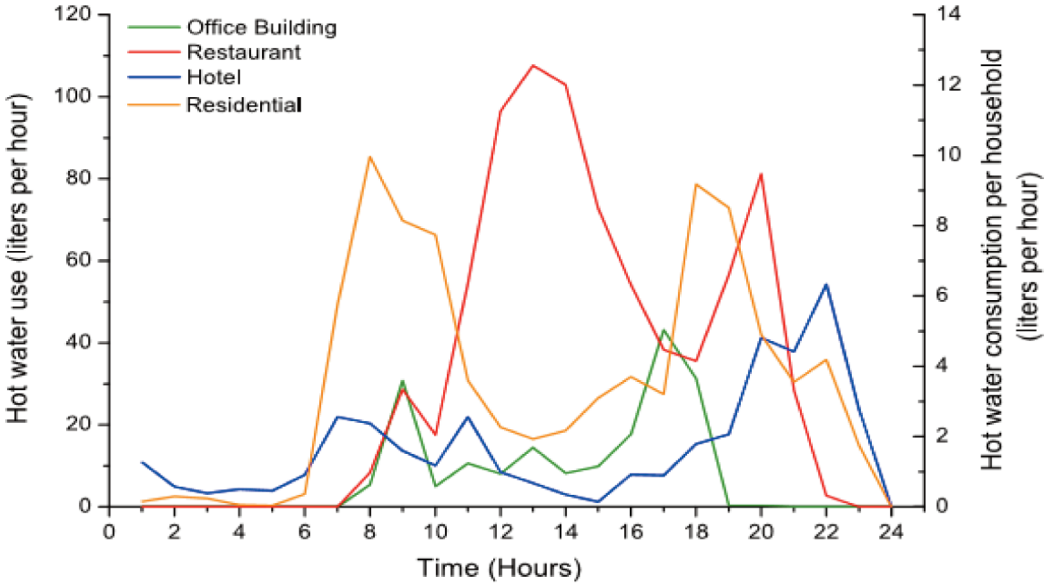

Figure 2. Average hourly DHW profiles for different building types, the residential profile type is represented on the right [20]

Modelling and sizing methods of sts for dhw application

Many researchers are developing predicting software and modelling tools for DHW consumption in the commercial buildings (hotels, hospitals, offices etc.) more than the residential buildings. The main reason of that is the lake of data-based sensors and the complexity of predicting occupant behaviour of residential buildings due to the huge number of uncertainties relevant to residential occupants [21]. Different methods have adapted to estimate/ forecast the demand for DHW and thus, offering the information for designing the adequate shape of STS. The popular sizing methods of STS for DHW demand in buildings are summarised as follows:

- –Technical standard based method,
- –Time series forecasting models,
- –Time series models based data-learning modelling methods (Artificial Neural Network (ANN)),
- –Stochastic models, and,
- –DHW consumption profiles based real database.

Table 5. Selected technical standards for designing the DHW, estimating the energy consumed and water profiles [22-23]

Technical Standard	Zone	Relevant information for DHW installations design
EN 15316	EU	Methods to determine the daily/yearly DHW volume requirements of a dwelling/ a building. It provides data on annual average mains water supply temperature for different European climates and locations
EN 12976-2	EU	Dimensioning and design of solar thermal facilities for DHW applications. It provides a relationship for the annual estimation of the mains water temperature following a sinusoidal function.
EN 12831-3	EU	Calculating the power and storage volume required for the dimensioning of domestic hot water systems (DHW). Calculation method of the energy needs for DHW-Systems for residential and non-residential buildings or a zone of a building.
EVS 835:2003	Estonia	Estimation of domestic water installations design values for Estonian buildings.
AICVF	France	Guidelines about dimensioning sanitary water facilities. Annual estimations of DHW energy consumption for different buildings. Estimations of water consumption for different type of buildings.
VDI 4655	Germany	Guideline that supplies reference DHW load profiles as a basis and tool for the design of combined heat and power systems in residential buildings. It covers single-family houses for up to 12 occupants and multi-family houses with up to 40 flats.
UNE 94002	Spain	Design and dimensioning of solar thermal facilities for DHW applications. It provides equations for the monthly estimation of the DHW energy demand as a function of the occupancy, data of average DHW consumption per person and day for different buildings and monthly average mains water temperature data
CTE DB HE4	Spain	Technical guideline for the design and installation of DHW solar thermal facilities in buildings
BS 6700	UK	Design, installation and maintenance of services supplying water for domestic use inside buildings

The technical standards offer guideline information to design and size the DHW system based on nominal consumption values for the end-use devices. Moreover, the standards give an information for daily consumption per person in different types of buildings, residential buildings in particular. Table summarised several technical standards for the EU countries regarding DHW. A study investigated the accuracy of the technical standards for estimating DHW consumed by a residential building located in UK [22]. The study presented 5- dynamic models based national and international standards and used the same input data regarding the building case study. The results of each tool compared against the real consumption profiles of the building based on different variables (volume of water, energy consumption and losses, system efficiency, temperature of produced hot water etc.) and showed as underestimate as -30% for some tools and overestimation up to 40% for others of system sizing when compared to the measured data of case study.

For time series method (TSM), the future estimation of building consumption can be forecasted based on the historical profiles of the system. Such method showed good outcomes regarding DHW consumption in buildings. Other study used this method to analyse the results they had from previous study of a Finnish apartment buildings [24]. The study applied in the weekdays (WD) and weekend (WE) of the month of August and November. The generated data based TSM showed close behaviour of consumption profiles based on the previous work profiles and indicated accurate hourly consumption profiles of the current case study which showed effectiveness after validated against the measurements. The predicting of DHW consumption also can be done based on data learning methods like Artificial Neural Networks (ANNs). Such models found to be able to predict the profile consumption as they have the ability to approximate the non-linearity of DHW behaviour in buildings. ANN algorithm used to predict the end-use demand of a household (toilet tap, clothes water, dishwasher and bath demand) taking household income, number of adults, number of children, number of teenagers, and appliance efficiency as key determinants [25]. The study indicated that the ANN based modelling is a feasible method to forecast the end-use demand for residential buildings.

Stochastic models used to estimate DHW profiles depending on monitoring application data and survey information. Such method uses data usage based time to determine the probability of user activities and the energy used by these activities. Then, the probability calibrated with the measurements of consumption and time use data. A study constructed a stochastic end-use model to study the DHW profile for a single family house. The model simulated the diurnal DHW for each minute of a day using database offered by previous international study. Furthermore, the model indicated accurate data of DHW demand compared to the previous studies [26].

A group of scientists claim the estimation of DHW consumption profiles based modelling techniques as it rely on a set of engineering expectations so, the real collected data is more reliable than stochastic data-based. A study discussed the DHW profiles based on the database of Halifax Regional Municipality's Solar City project, Canada [27]. The study dealt with the hot water flow rate and its temperature for 119 homes. The study concluded that the average DHW consumption/ home is 172 l/day with high dependency on occupant's number, the peak load is twice daily, consumption on Sunday is the higher during the week and the average draw temperature of DHW is 51.8 oC which is lower than the temperature proposed in simulation/ modelling tools for DHW forecasting (55 °C).

Case studies

The body of literature has many case studies of STS for DHW application in buildings. Most of case studies based software work and only limited number dealing with real case studies. Table 6 details some important technical parameters of STS fabricated mainly for delivering hot water to a domestic usage purposes.

Conclusion

This article presented a general overview of the STS for DHW application in several building types. The main aspects pointed within the article were: the general shape of STS including the main element types used, DHW profiles and consumption pattern in the end-use draws, the main sizing and modelling methods adapted for forecasting hot water demand and finally, operational parameters of STS used for this purpose have indicated for several case studies.

The statistics of this research showed the importance of DHW application in building sector where the people spending about 80% of their life. Several conclusions drawn from the review of different studies mentioned in the body of this work, they can be summarised as following:

–Most of research work focused on DHW consumption and energy used in residential buildings and less attention has given to the other building types such as the restaurants, educational buildings, and airport lounges etc.

–There are many complex methods and modelling tools developed to forecast the hot water demand with no specific method for better estimating of STS size.

–Long-term solar DHW consumption prediction studies are missed as the human behavior and consumption needs are changing with time and should taking into account.

–Most of the reviewed case studies showed underestimating of solar systems which is mainly because the fluctuating of available solar radiation and that may call the attention to adapt another renewable source for water heating.

Table 6. Residential building case studies dealing with STS technical parameters

Reference	Region/ Location	Building type/ Load	Determinant parameters	Shape of STS and main outcomes of study
(Polo V.& Cesare B., 2018)	Italy (**Bolzano**, Turin, **Bologna**, Rome, Brindisi and Trapani)	residential building of 20 apartments (48 people) (□50/p/ day at 38 °C)	Period of year, day of week, climate condition for each city	Coll. area (m^2) (No. of coll.): FPC *37.12 (16), ** 46.4 (20); ETC 17.94 (6) Storage volume (m^3): FPC 5; ETC 4.5 Solar Fraction %: FPC 51.4 / 52.0; ETC 51.2 / 50.1 *Bolzano & **Bologna - Angle of inclination of 45°
(M. Zukowski, 2017)	Poland, (Bialystok)	Hotel (Campus)	Basic parameters of ambient air and solar radiation	-35 FPC & 21 ETC (total area of 146.29 m^2) - 8 Storage tanks of (1 m^3) - SF is 23.4% - System efficiency is 34.7% in warm months and 24.2% in cold months
(M. Ghorab et al., 2017)	Canada	-Family house (two adults and two kids) -(172-324 l/day) at 52.2°C	DHW draws, time & duration of draws, , city water temperature, and outside weather conditions	- 2 FPC of 2.858 m^2 for each (62.48°C to 86.4°C) - 91.5% of the collected solar energy is transferred to the DHW load. 8.5% heat loss from the storage tank -Highest SF around 45.44% - 30.6% solar share with 69.4% from auxiliary gas heater
(Allouhi A. et al., 2015)	Morocco, (**Errachidia**, Agadir, Marrakech, Tangier, Fez & Ifran)	-Individual family house (5 occupants) -(240 l/day, at 45 °C)	The location and climatic parameters	- FPC & ETC used, the ETC is better performance than FPC - Stratified storage tank (sensible) - The average value of SF is 72% FPC and 82% for ETC (Errachidia)

References

[1] **Knight IK, Manning N, Swinton M, Hajo MR** (2007). European and Canadian non-HVAC electric and DHW load profiles for use in simulating the performance of residential cogeneration systems, Energy conservation in buildings and community systems programme. IEA Annex 2007; 42 (6):84.

[2] **Bennett C, Steward R, Beal C** (2013). ANN-based residential water end-use demand forecasting model. Expert Syst Appl, pp.1014–23.

[3] **Fairey P, Parker D.** (2004), A review of hot water draw profiles used in performance analysis of residential domestic hot water systems. In: FSEC RR-56-04, Cocoa, FL: Florida Solar Energy Center.

[4] **Barbern R, Egea P, Gracias-de Rentera P, Salvador M.** (2013), Evaluation of water saving measures in hotels: a Spanish case study. Int J Hosp Manag, Vol, pp. 34:181–91.

[5] **Abhishek G., Sunil C., Alok K., Satyendra Singhc** (2017), A review on technical improvements, economic feasibility and world scenario of solar water heating system, Renewable and Sustainable Energy Reviews, Vol. 68, pp. 542-562.

[6] **Bertrand A, Mastrucci A, Schler N, Aggoune R, Marchal F** (2016), Characterisation of domestic hot water end-uses for integrated urban thermal energy assessment and optimisation, Applied Energy. In press.

[7] **Agnieszka Chmielewska, Małgorzata Szulgowska-Zgrzywa, and Jan Danielewicz** (2017), Domestic hot water consumption in multiapartment buildings, E3S Web of Conferences 17, 00014 (2017).

[8] **Andrea F., Kaiser Ahmed, Petri Pylsy, Jarek Kurnitski** (2017), Analytical modelling and prediction formulas for domestic hot water consumption in residential Finnish apartments, http://dx.doi.org/10.1016/j.enbuild.2017.03.021

[9] Bohdanowicz P, Martinac I. (2007), Determinants and benchmarking of resource consumption in hotels. Energy Build. Vol. 39, pp.82–105.
[10] Jordan U, Vajen K (2001), Realistic Domestic Hot-Water Profiles in different time scales, Solar Heating and Cooling Program of the International Energy Agency (IEA SHC), Task 26: Solar Combisystems.
[11] Bujak J (2010). Heat consumption for preparing domestic hot water in hospitals. Energy Build, Vol. 42, pp.1047–1055.
[12] Hendron R, Burch J, Barker G (2010), Tool for Generating Realistic Residential Hot Water Event Schedules, SimBuild 2010, New York, August 1519. Conference Paper NREL/CP-550-47685 August 2010.
[13] Kadir Amasyali, Nora M. El-Gohary (2018), A review of data-driven building energy consumption prediction studies, Renewable and Sustainable Energy Reviews, Vol. 81, pp.1192-1205.
[14] Marini D, BR, Hopfe C (2015), A critical software review- how is hot water modelled in current building simulation?. Proceedings of the 14th International IBPSA conference, Hyderabad, India, 7–9 December 2015.
[15] Defra Report (2008), Department of Environmental, Farming, and Rural Affairs, Measurement of Domestic Hot Water Consumption in Dwellings.
[16] Hamele H, Eckard S. (2006), Environmental initiatives by European tourism businesses, 2006.
[17] Deng S. (2003), Energy and water uses and their performance explanatory indicators in hotels in Hong Kong. Energy Build., Vol. 5m pp. 775–84.
[18] Ahmed K., Pylsy P, Kurnitski J (2016), Hourly consumption profiles of domestic hot water for different occupant groups in dwellings, Solar Energy, Vol. 137, pp. 516–30.
[19] Allouhi A, Jamil A, Kousksou T, El Rhafiki T, Mourad Y, Zeraouli Y (2015). Solar domestic heating water systems in Morocco: an energy analysis. Energy Convers Manag, Vol. 92, pp.105–113.
[20] Dzintars Grasmanis, Normunds Talcis, Aldis Grekis (2015), Heat Consumption Assessment of the Domestic Hot Water Systems in the Apartment Buildings, Proceedings of REHVA Annual Conference 2015 "Advanced HVAC and Natural Gas Technologies" Riga, Latvia, May 6 – 9, 2015.
[21] Fuentes E., L. Arce, J. Salom (2017), A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis, Renewable and Sustainable Energy Reviews, http://dx.doi.org/10.1016/j.rser.2017.05.229, in press.
[22] George D, Pearre NS, Swan LK (2015). High resolution measured domestic hot water consumption of Canadian homes. Energy Build, Vol. 105, pp. 304–315.
[23] Hazami Majdi, Kooli Sami, Naili Nabiha, Farhat Abdelhamid (2013), Long-term performances prediction of an evacuated tube solar water heating system used for single family households under typical Nord-African climate (Tunisia), Solar Energy, Vol. 94, pp. 283–98.
[24] Hauer, A. (2011), Storage Technology Issues and Opportunities, International Low-Carbon Energy Technology Platform. In Proceedings of the Strategic and Cross-Cutting Workshop "Energy Storage—Issues and Opportunities", Paris, France, 15 February 2011.
[25] IEA (2019), Renewables 2018: Market analysis and forecast from 2018 to 2023, https://www.iea.org/renewables2018/heat/.
[26] Janusz Bujak (2010), heat consumption for preparing domestic hot water in hospitals, Energy and Buildings, Vol. 42, pp. 1047–1055.
[27] Marwan AL-Khaffajy and Ruth M. (2013), Optimization of the heat exchanger in a flat plate indirect heating integrated collector storage solar water heating system, Renew Energy, Vol. 57, pp. 413–21.
[28] M. Ghorab, Evgueniy Entchev, Libing Yang (2017), Inclusive analysis and performance evaluationof solar domestic hot water system (a case study), Alexandria Engineering Journal, Vol. 56, Issue 2, pp. 201-212
[29] M. Zukowski (2017), Energy efficiency of a solar domestic hot water system, E3S Web of Conferences 22, 00209 (2017), DOI: 10.1051/e3sconf/20172200209.
[30] M.C.Rodríguez-Hidalgo, P.A.Rodríguez-Aumente, A.Lecuona, M.Legrand, R.Ventasb (2012), Domestic hot water consumption vs. solar thermal energy storage: The optimum size of the storage tank, Applied Energy, Vol. 97, pp. 897-906.
[31] Morné Richard (2016), Simulating Domestic Hot Water Demand by means of a Stochastic End-Use Model, M.Sc. thesis, https://pdfs.semanticscholar.org/c8d6/b9b9344af6eed4533e85d6e31d159c23e316.pdf
[32] Solar Energy Industries Association (SEIA) (2016), https://m.huffpost.com/us/entry/us_8134790
[33] Sunflower renewable energy company, LTD (2019), Comparison between Evacuated Tube Collector & Flat Plate Collector. http://www.sunflower-solar.com/index.php?act=content&scheduler_id=390.

[34] Tortella B, Tirado D. (2011), Hotel water consumption at a seasonal mass tourist destination. The case of the island of Mallorca. J Environ Manag., Vol. 92, pp. 2568–2579.
[35] Ulseth R, Alonso MJ, Haugerud P. (2014), Measured load profiles for domestic hot water in buildings with heat supply from district heating. In: Proceedings of the 14th International Symposium on District Heating and Cooling, September 7–9. Stockholm, Sweden, 2014.