Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by
Center for Solar Energy Research and Studies

Legionella Bacteria Activity investigation in Domestic Water Heating Systems: Tripoli-Libya as a case study

Abdulmaged Algareu[1], Mohammad Abdunnabi[1], Maged Mabruk[1], and Adel M. Elmaghrabi [2,3]

Libyan Center for Solar Energy Research and Studies, Tripoli, Tajura-Libya

[2]Alhadira University, Tripoli-Libya

[3]Biotechnology Research Centre, Tripoli-Libya

Email: Abdulmaged.algareu@csers.ly

Abstract: Legionella is a kind of bacteria that has been detected by many researchers in different Water Heating Electrical (EWH) or solar (SWH) systems installed at various places. In the capital city Tripoli - Libya, most of water heater systems used are of electric type. Simultaneously, over 100 solar water heating (SWH) systems provided with electric heaters were installed under the supervision of the Centre for Solar Energy Research and Studies (CSERS) in the residential buildings in Tripoli in the period between (2000 and 2020). Ten hot water samples were collected from the outlet points in SWH systems and 43 water samples from different water draining points at Corinthia hotel and Palm City Residences water systems, for the purpose of legionella detection and enumeration in the systems. A questionnaire was designed and distributed to be filled by the 10 SWH system users whom the ten water samples were taken from. The purpose was to collect information about the building, the hot water system, and the user's satisfaction. As the water source is untreated ground water from private wells, analysis of Escherichia coli (E.coli), total Coliform bacteria and total bacterial count were conducted to see whether any other probable bacteria kind is available. According to the results obtained, both 43 samples and 10 SWH samples investigated are free of legionella bacteria, while the total bacteria count for 4 out of 10 SWH systems was less than 60 CFU/g. This was due to water temperature not lowered to the bacteria colonisation temperature, and the daily water temperature gained from solar energy was high enough to be more than 55°C for at least an hour daily and maximum daily temperature exceeds 60°C for 80 days in addition to summer time, which is high enough to destroy legionella bacteria

* *Corresponding author*

DOI: 10.51646/jsesd.v10i2.114

دراسة نشاط بكتيريا الليجونيلا في منظومات تسخين المياه المنزلية: طرابلس ـ ليبيا (دراسة حالة)

عبدالمجيد عمر القريو [1]، محمد جمعة عبدالنبي [1]، ماجد المبروك [1]، عادل المغربي [2]

[1] المركز الليبي لبحوث ودراسات الطاقة الشمسية . طرابلس. تاحوراء ـ ليبيا

[2] الجامعة الحاضرة، طرابلس - ليبيا

[3] المركز الليبي للتقنيات الحيوية، طرابلس ـ ليبيا

ملخص:الليجونيلا (Legionella) هي نوع من البكتيريا التي تم الكشف عنها من قبل العديد من الباحثين في مختلف أنظمة تسخين المياه الكهربائية (EWH) أو التي تعمل بالطاقة الشمسية (SWH) المثبتة في أماكن مختلفة. في العاصمة طرابلس – ليبيا، معظم أنظمة سخانات المياه المستخدمة هي من النوع الكهربائي. وقد تم تركيب حوالي ١٠٠ نظاماً لتسخين المياه بالطاقة الشمسية مزودة بمسخن كهربائي مساعد تحت إشراف المركز الليبي لبحوث ودراسات الطاقة الشمسية. تمت دراسة عينات مياه مسجوبة من ١٠ منظومات تسخين بالطاقة الشمسية و٤٣ منظومة تسخين كهربائية مركبة بكل من فندق كورونثيا ومدينة النخيل السكنية بطرابلس للتأكد من إمكانية وجود بكتيريا الليجونيلا في هذه المنظومات. وقد تم تصميم وتوزيع استبيان وتعبئته من قبل مستخدمي نظام SWH الذين تم أخذ عينات المياه العشر منهم لأخذ معلومات عن المنظومات ووطريقة تشغيلها ومدى رضا المستخدمين لها.

أظهرت نتائج تحليل العينات أن جميع المنظومات التي تمت دراستها خالية من بكتيريا الليجونيلا، والبكتيريا الإشريكية القولونية (E.coli)، وأن العدد الإجمالي للبكتيريا لا يتجاوز 60 CFU/g، على الرغم من أن مصدر المياه المغذي لمنظومات التسخين بالطاقة الشمسية هو المياه الجوفية غير المعالجة والقادمة من الآبار الخاصة. ويرجع ذلك إلى أن درجة حرارة المياه لم تنخفض إلى درجة حرارة تكاثر البكتيريا لفترة طويلة، وأن درجة حرارة المياه اليومية المكتسبة من الطاقة الشمسية كانت عالية لتصل إلى أكثر من ٥٥ درجة مئوية ودرجة الحرارة القصوى اليومية تتجاوز ٦٠ درجة مئوية لحوالي ٨٠ يوماً خلال فصل الصيف، وهي عالية بما يكفي لتدمير بكتيريا الليجونيلا.

Keywords: *Solar water heating, Legionella Bacteria, Maximum daily temperature*

1. INTRODUCTION

1.1 Domestic Water Heating

Domestic water heating (DWH) is the process of warming water for domestic use, and it can consume a large amount of energy. The consumption of DWH varies across cultures. Recently utilizing solar water heating systems in the residential sector is arguably one of the most energy-efficient technique of producing domestic hot water, as the primary source “sunlight” for energy is renewable, competitive and cost effective. Most solar water heaters come with auxiliary heaters that make users benefit from reduced running out of hot water[1][2] [3]. Also, some SWH do not require electricity to operate, where systems are directly used to heat water, as in the swimming pool applications to extend the outdoor swimming season [4].

Solar water heating systems are classified according to how the heat transfer fluid flows through the collector, or how the water is heated. Two basic types of solar water heating systems, which are ; Direct (open loop) and Indirect (closed loop) water heating system which can be passive or active [1]. Active system uses a pump to circulate working fluid between the tank and the collectors, while passive SWH depends on natural convection for circulation. Natural convection systems are either integral collector-storage or thermosiphon systems. The integral type is more suitable for climates where temperature often drops below freezing [2].

According to the International Energy Agency data, the solar thermal total capacity installed 410.2 GWth by the end of 2014 which is equivalent to 586 million square meters of collector area[5], and grew to 479 GWth that equivalent to 684 million square meters by the end of 2019 [6]

In Middle East and North Africa (MENA) region that with 21 countries, the solar water heating systems are about 9 million square meters of collector area demonstrating and counts about 6.3 GWth of installed capacity. In part MENA countries; Palestine is the leader with 1,120 MWth followed by Egypt, Tunisia, and Syria respectively [5]. In Libya, little attention was given to the study and use of solar energy for water heating in the last few decades; simultaneously, a few PV systems were installed by oil companies in Libya for oil pipelines protection [7] and recently, some small PV solar systems were installed in some remote areas in Libya, but with increase of electricity cut off crisis, more attention is paid towards using solar energy.

Domestic water heating in Libya accounts for 29 % of the whole electrical consumption in the residential sector [8]. Also, a great potential of hot water usage is in the industrial and other sectors [9]. Solar Water Heating (SWH) system is one of the promising thermal systems to be used in Libya. Although suitable working climate is available during the year, SWH systems are not widely spread. One of the drawbacks of these systems is the high up-front cost of the systems, and recently concern of water contamination by some type of germs as a result of water stagnation and heating temperature when is not exceeding 60 °C [10].

1.2 Legionella Background

Legionella is a kind of bacteria have been discovered after an outbreak in 1976 among people in Philadelphia convention, USA [11]. Legionella can cause respiratory illness to humans termed legionellosis [12]. Clinically, two disease forms were distinguished as stated by Anna Domańska: severe atypical pneumonia also called Legionnaires' disease, and the mild flu-like Pontiac fever that ends with spontaneous recovery [13]. The mortality rate of Legionellosis is quite high between 5–30% [14]which is called Anti Bacteria Heat Exchanger (ABHE. Legionella detected by many researchers in different hot water systems installed at various places. Recently, the Legionella growth is considered in the design of hot water systems for domestic heating and space heating by many researchers [15]. Other researchers investigated the legionella growth in the existing hot water systems, and the methods of prevention. Nostro et al in 2011 [16] investigated the contamination of hot water systems by legionella at hospitals, hotels, nursing homes, factories and spas in Tuscany – Italy, as part of surveillance and control. For three years, 493 water samples were taken from 14 structures, including three hotels, three hospitals, three nursing homes, two factories and three spas with thermal springs. Collecting water samples was from the most distal taps, hot water tanks and near endplate pipes, where water stagnation would happen. Results showed that the water temperature was 45 °C for samples taken from hotels and thermal springs and 36% and 31.7% of 30 and 41 samples were contaminated, respectively. Water temperature was below 48 °C for the samples taken from hospitals nursing rooms and 67.1% and 23.8% from 155 and 164 samples were contaminated, respectively. Also, 50% of the 20 samples taken from factories were contaminated. Control of contamination using thermal shock at 80 °C was used and a recolonization was found at temperature below 50 °C after one year of thermal disinfection. About ten-year experience report was written by Marchesi, et al [17] for water decontamination methods using hyper-chlorination, thermal shock, chlorine dioxide, mono-chloramine, boilers and point-of-use filters to eliminate legionella infection in a hospital water heating system. Thermal shock decontamination was related to the pre-treatment contamination levels return in one or two months. 432 hot water samples were collected from different points including return loops, storage tanks and distal showers and taps, in the way without flaming and after flushing for 1 min, measuring water temperature and chlorine levels at free chlorine, chlorine dioxide and/or mono-chloramine. Report mentioned that chlorine dioxide-maintained levels at <100 CFU/L and satisfactory results with mono-chloramine. on the other hand, no contamination was found using point-of-use filters and electric boilers at temperatures of more than 58 °C and no cases of Legionnaires' disease were spotted during the ten-year surveillance period. Effective methods of stopping legionella growth is also reported by Gevari et al [18]namely, heat transfer, surface cleaning and fouling, water treatment, food industry, chemical reactions, energy harvesting. A considerable

$$B = B_n \cos(\theta_z) \quad \text{..... (1)}$$

amount of energy in the mentioned industries is required for thermal applications. Cavitation could serve for minimizing the energy demand and optimizing the processes. Thus, the energy efficiency of the systems could be significantly enhanced. This review article focuses on the direct and indirect thermal applications of hydrodynamic and acoustic cavitation. Relevant studies with emerging applications are discussed, while developments in cavitation, which have given rise to thermal applications during the last decade, are also included in this review.","author":[{"dropping-particle":"","family":"Gevari","given":"Moein Talebian","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Abbasiasl","given":"Taher","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Niazi","given":"Soroush","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Ghorbani","given":"Morteza","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Koşar","given":"Ali","non-dropping-particle":"","parse-names":false,"suffix":""}],"container-title":"Applied Thermal Engineering","id":"ITEM-1","issued":{"date-parts":[["2020"]]},"page":"115065","title":"Direct and indirect thermal applications of hydrodynamic and acoustic cavitation: A review","type":"article-journal","volume":"171"},"uris":["http://www.mendeley.com/documents/?uuid=6c46f8cb-be8a-424a-9230-cc16fc83e589"]}],"mendeley":{"formattedCitation":"[18]","plainTextFormattedCitation":"[18]","previouslyFormattedCitation":"[18]"},"properties":{"noteIndex":0},"schema":"https://github.com/citation-style-language/schema/raw/master/csl-citation.json"}. In Germany, Mathys, et al [19] analysed 452 samples of hot water for single family houses testing different plumping systems (copper, synthetic materials and galvanised steel) to investigate the occurrence of legionella in water systems. Results showed that for houses use instantaneous water heaters where no Legionella is found, while about 12% in houses with storage tanks and recirculating hot water where maximum counts of Legionella reached 100,000 CFU/100ml. Also, copper plumping systems are more contaminated than other plumping systems, and concluded to systems with significant lower hot water temperature is the main factor leading to increased colonisation of Legionella. In South Africa, Stone, et al [20] studied the potential infection rate of Legionellosis in low- and middle-income countries using Computational fluid dynamics (CFD) model. This mimics the methods of risk assessment based on temperature diagnostics for legionella growth and the elegant thermal regulation systems. Armstrong et Al [21] studied the balance between thermal and sanitary performance of stratified and de-stratified domestic hot water storing systems. Results showed that although a drop of about 19 % in de-stratified system thermal performance compared with stratified water storage systems, stratified systems revealed a calculated probability value ($P < 0.01$) of a bacterial growth between the bottom and top of storage tank. According to previous research studies, Legionella can be found in water temperature above 5°C , but starts to colonise in water temperature between 20°C to 60 °C [22][23] and can survive in temperature of up to 66°C for several minutes [24]. Legionella can also be prevented by maintaining the temperature of the hot water at 60 °C for about two hours per day [25].

Consequently, the installed systems need to be investigated for the occurrence of legionella.

In the capital city Tripoli - Libya, most of water heater systems used are of electric type with storage capacity ranging from 30 Litres to 80 Litres, and water temperature setup is between 60°C to 80°C. On the other hand, over 100 solar water heating systems provided with electric heater were installed under the supervision of Centre for Solar Energy Research and Studies (CSERS) in Tripoli. Recommendations by the centre is to set the auxiliary electric heater working temperature not exceeding 50°C, and works only when solar heated water temperature drops down this temperature, which make an assumption for legionella to colonise. This research study, is considered as key study for such systems in terms of the existence of legionella in water heating systems for either EWH or SWH installed in Libya before the widespread implementation of this technology.

2. METHODOLOGY

This paper investigates the existence of legionella in the SWH and EWH systems, by taking samples from different water heating systems installed in the capital city Tripoli Libya. In addition, detailed information

about the 10 SWH systems are to be collected using designed questionnaire, and to be filled by the 10 SWH systems' users.

2.1 Investigated SWH Systems Description

10 solar domestic water heating systems were randomly selected out of 100 systems installed in the capital city Tripoli – Libya by the CSERS, to be investigated in terms of availability of legionella bacteria. A sample of investigated systems are shown in Figure 1, and the technical specifications of the whole investigated systems are listed in Table 1. These systems are provided with additional electric heater element inside the water storage tank that was adjusted to keep hot water within 40°C to 60°C.

Figure 1 A sample of Investigated SWH systems installed in Tripoli-Libya. A: Calpak (FPC), B:Calpak (ETC), C: SHE (FPC) and D: Megasun (FPC)

Table 1 Solar water heating (SWH) systems investigated in terms of availability of Legionella and other bacteria

Manufacturer	Capacity (L)	Number of collectors	Total collector area (m^2)	Installation year	Number of SWH systems
Calpak (FPC)	200	2	4.42	2012	1
Calpak (ETC)	200	1	2.5	2013	2
Softan	300	2	4	2013	2
Solar 23	200	2		2018	1
Megasun	200	1		2018	1
Dimas	200	2	2.2	2012	1
Dimas	300	2	4	2012	1
SHE	200	1		2018	1

2.2 Sample collection

10 samples were collected from the water outlet point in the system after 1 minute of water drainage, and then filled in two groups of sterilised (500 mL for bacteriology use only). The first six group samples were collected in the 26th of December 2019, while the second four group samples were collected in the 10th of March 2020. Samples were sent to the Aldeqqa Aljadeeda for Food Analysis laboratory in Tripoli, within less than three hours of time. Detection and enumeration of legionella Spp analysis was conducted with preparation and incubation of sample plates, according to the procedure for the recovery of legionella from the Environment Centres for Disease Control and Prevention (CDC) issued in January 2005 and ISO 11730-2 [26]. Figure 2 shows the Memmer incubator used in the analysis process of water samples collected.

Figure 2 Memmer incubator used in legionella test

2.3 Designed Questionnaire

A questionnaire was designed and distributed to be filled by the targeted SWH system users whom the water samples were taken from. That was to collect information about the regions where system installed, design of building, number of people living in the building, water source, water salinity, number of bathrooms

and kitchens fed by SWH system, number of bathrooms and kitchens fed by Electric water heating (EWH) system, installation year, system working status, as well as the users' satisfaction of using SWH system and problems faced during system working period.

2.4 Corinthia Hotel and Palm City Residences Samples.

Also, Water at different water draining points were collected from Corinthia Hotel and Palm city Residences in the capital city Tripoli -Libya, for the purpose of Legionella existence analysis. 32 water samples were collected in the 27th of June 2013 from Corinthia Hotel at different water draining points in the building including raw water tank, water drain and return points at different hotel floors, fire tanks (general and laundry) water points and irrigation system. On the other hand, 11 water samples were collected in the 26th of February 2018 from Plam city Residences at different water draining points including shower water and tap water. Samples were analysed at the same laboratory, Aldeqqa Aljadeeda.

3. RESULTS AND DISCUSSION

3.1 Questionnaire information results and discussion

According to the information collected from the ten SWH system users by the questionnaire, it is found that the average people living in each building is about 5 people and most of buildings are of private house with one floor, the main water tank is placed on the stair room. The water source of all ten houses is from private well, untreated water and pure or little to medium water salinity. The average of bathrooms fed of hot water by the SWH is about 2 bathrooms per house, while kitchens are one to two kitchens per house. On the other hand, no EWHs are used in these houses. The ten systems chosen for this study were installed in different periods between 2012 and 2018, and all of them are in good working conditions except part of them had a defect in the auxiliary electric heating element while some users did not need it. Therefore, auxiliary electric heating element was either switched off or not connected to electricity source. About the satisfaction of users, all of them were satisfied by the SWH system as a good alternative heating device to EWH systems that widely spread in Libyan state, and have the advantage of working renewably.

3.2 Bacterial analysis results of SWH systems

As discussed in the collected information about water source, SWH feeding water comes directly from private well and no treatment was applied on water entering the system. Therefore, besides legionella detection analysis, analysis of Escherichia coli (E.coli), total Coliform bacteria and total bacterial count were conducted to see whether any other probable bacteria kind is available. The optimum growth temperature of Escherichia coli is 37°C and can grow at temperatures up to 49°C as also observed to be alive at 53°C [27] .

Table 2 lists the results of ten samples, obtained from the analysis process. The results include the total bacteria count per millilitre (as colony forming unit per gram, CFU), the total coliform bacteria, E. coli per millilitre and the detection and enumeration of legionella species (spp). It is clearly shown that the ten samples analysed are free of any detected legionella bacteria, for the whole samples analysed, as well as the E. coli/mL. On the other hand, the total coliform bacteria per mL was less than 60 CFU/ g for the four samples group and absent for the rest six sample group.

The free legionella results obtained in this study might be interpreted from the results obtained by the recorded data (every half an hour) from a system installed by the CSERS, shown in Figure 3 [28]. The results show that all over the year, the average maximum daily temperature is about 55.5 °C and over 80 days excluding summer time, the water temperature exceeds 60°C for at least one hour per day. This is might enough reason to supress legionella growth.

Table 2 Analysation results of ten water samples for SWH systems in Tripoli.

S.N	Sample Code	Sample type	Total Bacteria Count/mL	Total Coliform Bacteria/mL	E.coli/mL	Detection & Enumeration of Legionella spp
1	WS-19-115	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
2	WS-19-116	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
3	WS-19-117	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
4	WS-19-118	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
5	WS-19-119	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
6	WS-19-120	Water from SWH system	<10 CFU/g	Absent	Absent	Not Detected
7	WS-20-010	Water from SWH system	15 CFU/g	Positive	Absent	Not Detected
8	WS-20-011	Water from SWH system	60 CFU/g	Positive	Absent	Not Detected
9	WS-20-012	Water from SWH system	10 CFU/g	Positive	Absent	Not Detected
10	WS-20-013	Water from SWH system	25 CFU/g	Positive	Absent	Not Detected

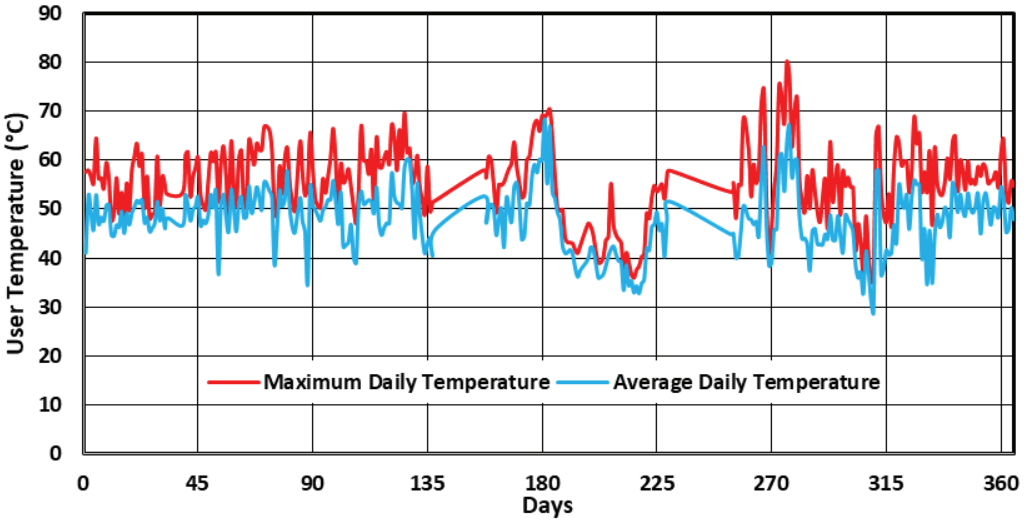

Figure 3 users maximum daily temperature and average daily temperature of water discharged from the system tank

3.3 Bacterial analysis results of Corinthia Hotel and Palm City Residences.

According to the analysis based on CDC procedure, results showed that neither detection nor enumeration for the legionella bacteria in the 43 samples collected from both Corinthia Hotel (June 2013) and Palm city residences (February 2018). This is also indicating that the chance for legionella growth in the water systems is too slim, at least in the general residential (hotels residences) water source. The reason is that both residences use electric heaters and gas boilers for their heating systems and the water temperature is most of the time is over 60°C.

4. CONCLUSIONS

According to the results obtained from the questionnaire and the 53 samples analysis, it is concluded that all 53 samples analysed are free of legionella bacteria. Although water source for the 10 investigated SWH systems is an untreated groundwater coming from private wells, E. coli bacteria, and the total bacterial count not exceeding 60 CFU/g. This is due to water temperature not lowered to the bacteria colonisation temperature, and the daily water temperature gained from solar energy was high enough to be more than 55°C for at least an hour daily and maximum daily temperature exceeds 60°C for 80 days in addition to summer time, which is high enough to destroy legionella bacteria. Users were satisfied to use SWH system as a good alternative heating device to EWH systems that widely spread in Libyan state, and have the advantage of working without electrical source (renewably).

It can be concluded that the threaten of emerging legionella due to the taking –up SWH system over EWH systems which comes from that most of the SWH users don't make use of auxiliary electric heater to set the water temperature up to 60 °C is slim. However, this study is to be considered a reference study, and setting frequent studies with widen study area and collecting larger number of samples is essential, to trace the legionella in the building hot water systems in Libya.

ACKNOWLEDGEMENT:

The authors are thankful to Alhadira University for the financial support to achieve this research by providing most the facilities.

REFERENCES

[1]. K. Patel, P. Patel, and J. Patel, "Review of solar water heating systems," Int. J. Adv. Eng. Technol., vol. 3, no. 4, pp. 146–149, 2012.

[2]. M. Hazami, A. Riahi, F. Mehdaoui, O. Nouicer, and A. Farhat, "Energetic and exergetic performances analysis of a PV/T (photovoltaic thermal) solar system tested and simulated under to Tunisian (North Africa) climatic conditions," Energy, vol. 107, pp. 78–94, 2016.

[3]. T. S. Vinubhai, R. J. Vishal, and K. Thakkar, "A review: solar water heating systems," in The National Conference on Emerging Vista of Technology in the 21st Century, Limda, Vadodara, 2014, pp. 1–8.

[4]. V. G. Shelke, C. V Patil, and K. R. Sontakke, "Solar Water Heating Systems: A Review ISSN (Online): 2347-3878," Impact Factor, vol. 3, 2014.

[5]. F. Mauthner, W. Weiss, and M. Spörk-Dür, "Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2014," 2016. [Online]. Available: http://www.iea-shc.org/data/sites/1/publications/Solar-Heat-Worldwide-2016.pdf.

[6]. W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide: Global Market Development and Trends in 2019," 2020. [Online]. Available: https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2020.pdf.

[7]. I. M. Saleh, "Prospects of renewable energy in Libya," Sol. Phys. Sol. eclipses (SPSE 2006), pp. 153–161, 2006.

[8]. M. J. R. Abdunnabi, K. Dadesh, O. R. Mrehel, and N. El-shamekh, "Effect of full implementation of domestic solar water heaters on the electricity peak load in Libya," Sol. Energy Sustain. Dev. J., vol. 5, no. 2, 2016.

[9]. M. Abdunnabi, I. Rohuma, E. Endya, and E. Belal, "Review on solar water heating in Libya," Sol. Energy Sustain. Dev. J., vol. 7, no. 3 SE-Articles, Feb. 2021, doi: 10.51646/jsesd.v7i3.76.

[10]. W. J. Rhoads, P. Ji, A. Pruden, and M. A. Edwards, "Water heater temperature set point and water use patterns influence Legionella pneumophila and associated microorganisms at the tap," Microbiome, vol. 3, no. 1, pp. 1–13, 2015.

[11]. E. Olsen, "2019 Legionnaires outbreaks: Another busy year for Legionella," Siegel Brill PA, 2019. https://www.legionnairesdiseasenews.com/2020/01/2019-legionnaires-outbreaks/.

[12]. D. Chauhan and S. R. Shames, "Pathogenicity and Virulence of Legionella: Intracellular replication and host response," Virulence, vol. 12, no. 1, pp. 1122–1144, 2021, doi: 10.1080/21505594.2021.1903199.

[13]. A. Sawczyn-Domańska, "Detection of Legionella spp. and occurrence of virulence genes: lvh, rtxAand enhC in water samples from artificial water systems," Ann. Agric. Environ. Med.

[14]. L. Altorkmany, M. Kharseh, A.-L. Ljung, and T. Staffan Lundström, "Experimental and simulation validation of ABHE for disinfection of Legionella in hot water systems," Appl. Therm. Eng., vol. 116, pp. 253–265, 2017, doi: https://doi.org/10.1016/j.applthermaleng.2017.01.092.

[15]. J. A. A. Engelbrecht, M. J. Ritchie, and M. J. Booysen, "Optimal schedule and temperature control of stratified water heaters," Energy Sustain. Dev., vol. 62, pp. 67–81, 2021.

[16]. A. Lo Nostro, E. Checchi, B. Ducci, and G. Pesavento, "Legionella contamination in hot water systems of hospitals, nursing homes, hotels, factories and spas in Tuscany-Italy," Ital. J. Public Health, vol. 8, no. 1, 2012.

[17]. I. Marchesi et al., "Effectiveness of different methods to control legionella in the water supply: Ten-year experience in an Italian university hospital," J. Hosp. Infect., vol. 77, pp. 47–51, Jan. 2011, doi: 10.1016/j.jhin.2010.09.012.

[18]. M. T. Gevari, T. Abbasiasl, S. Niazi, M. Ghorbani, and A. Koşar, "Direct and indirect thermal applications of hydrodynamic and acoustic cavitation: A review," Appl. Therm. Eng., vol. 171, p. 115065, 2020, doi: https://doi.org/10.1016/j.applthermaleng.2020.115065.

[19]. W. Mathys, J. Stanke, M. Harmuth, and E. Junge-Mathys, "Occurrence of Legionella in hot water systems of single-family residences in suburbs of two German cities with special reference to solar and district heating," Int. J. Hyg. Environ. Health, vol. 211, no. 1–2, pp. 179–185, 2008.

[20]. W. Stone, T. M. Louw, G. K. Gakingo, M. J. Nieuwoudt, and M. J. Booysen, "A potential source of undiagnosed Legionellosis: Legionella growth in domestic water heating systems in South Africa," Energy Sustain. Dev., vol. 48, pp. 130–138, 2019.

[21]. P. Armstrong, D. Ager, I. Thompson, and M. McCulloch, "Domestic hot water storage: Balancing thermal and sanitary performance," Energy Policy, vol. 68, pp. 334–339, 2014.

[22]. S. Amara, T. Baghdadli, B. Nordell, and R. Khimulu, "Solar system design for water treatment: antibacterial heat exchanger (ABHE)," in Innovative Healthcare Systems for the 21st Century, Springer, 2017, pp. 167–180.

[23]. [23] "Water Temperature Legionella," Legionella.ae, 2017. https://legionella.ae/legionella-breeding-ground/water-temperature-legionella/ (accessed Nov. 08, 2020).

[24]. S. Knapp and B. Nordell, "Energy-efficient Legionella control that mimics nature and an open-source computational model to aid system design," Appl. Therm. Eng., vol. 127, pp. 370–377, 2017.

[25]. J. Li, X. Li, R. Du, Y. Wang, and J. Tu, "A new design concept of thermal storage tank for adaptive heat charging in solar heating system," Appl. Therm. Eng., vol. 165, p. 114617, 2020.

[26]. "Procedures for the Recovery of Legionella from the Environment Centers for Disease Control and Prevention (CDC)," Atlanta, 2005. [Online]. Available: https://www.epa.gov/esam/procedures-recovery-legionella-environment.

[27]. U. Fotadar, P. Zaveloff, and L. Terracio, "Growth of Escherichia coli at elevated temperatures," J. Basic Microbiol. An Int. J. Biochem. Physiol. Genet. Morphol. Ecol. Microorg., vol. 45, no. 5, pp. 403–404, 2005.

[28]. M. Abdunnabi, "Solar Water Heaters Test Field Project," Tajoura, 2020.