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FIELD ASSESSMENT OF DOMESTIC SOLAR WATER HEATERS

PUBLIC ACTION FOR WATER, ENERGY AND ENVIRONMENT PROJECT

PROSPERITY, LIVELIHOODS AND CONSERVING ECOSYSTEMS (PLACE) IQC TASK ORDER #5

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PREFACE

The Public Action for Water, Energy and Environment Project (PAP) is a public education and behavior change communication program developed to support USAID's technical and policy investments in the Jordanian water and energy sectors, and to support specific initiatives in the environment, in particular with regard to solid waste. The project has been awarded to ECODIT, a US small business holding the Prosperity, Livelihoods and Conserving Ecosystems, or PLACE, Indefinite Quantity Contract with USAID.

PAP is a five-year-long program that has been designed with three phases:

1. Data collection and assessment phase of nine months ending July 31, 2010;
2. Participatory strategic planning phase of three months that will include dialogue with the relevant stakeholders; and
3. Implementation phase lasting about four years.

The first phase of the project (Assessment and Baseline Phase) is to be completed by the summer of 2010. As part of this phase, ECODIT is conducting numerous surveys, including 12 or more research efforts, and it is from the totality of these efforts that the project will determine its direction and focus on behavior change. ECODIT has divided this phase into the several rapid assessments. In addition to this survey, "Domestic Solar Water Heaters," which was prepared by Eco Engineering and Energy Solutions (EcoSol), other surveys include "Young People's Knowledge Attitudes and Behaviors on Environmental Issues: Water and Energy Conservation" and "Solid Waste Management." In the informal and non-formal sectors, water- and energy-related interviews are ongoing for large Jordanian consumers, KAP household, donors, NGOs/CBOs, commercial outlets, governmental institutions including ministries, municipalities and utilities, and educational programs.

This study is a field assessment of domestic solar water heaters in the city of Amman to measure the level of cold-water losses before the hot water reaches the end user.

The objectives of the project, as relevant to this survey and outlined by the Public Action for Water, Energy and Environment Project, are to:

1. Measure and calculate the cold-water losses (CWL) before the hot water reaches the end user on the household level.

2. Conduct a detailed situational analysis on the use and status of solar water heaters (SWH) from the customer point of view.

3. Propose applicable solutions to overcome the cold-water losses issue in Jordan.

The report consists of seven chapters and an executive summary. Chapter 1 covers the introduction and the research methodology; Chapter 2 presents the key findings; Chapter 3 offers a detailed analysis; Chapter 4 gives some general observations; Chapter 5 presents the recommendations; Chapter 6 includes the conclusion; and Chapter 7 includes the appendices (Appendix A: list of abbreviation; Appendix B: definitions; and Appendix C: the field assessment questionnaire).

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EXECUTIVE SUMMARY

This report contains detailed data and analysis about the level of cold-water losses (CWL) from solar water heaters (SWH) before the hot water reaches the end user in different types of residential units in Amman. The findings of this report are based on the thorough analysis of a survey conducted by EcoSol.

For this purpose, a representative sample of 155 residential units was visited by the EcoSol team in order to evaluate the installed solar water-heating system and to measure the cold-water losses at the most distant shower head.

The field survey was conducted by two teams. Each consists of one engineer as a team leader, one plumber and one female assistant. The main types of data obtained were:

- The residential apartment floor level and the total floors in the building.
- The distance between the solar water-heating system and the most distant showerhead.
- The amount of cold water discharged by the system before the hot water became available.
- Family size and the weekly average of showers.

More data and details were obtained, further details can be found in Chapter 3 of this report.

The two teams visited different apartment floor levels. Of the 155 apartments, 58 apartments were located at the first equivalent-floor level, 33 apartments were located at the second equivalent-floor level, 33 apartments were located at the third equivalent-floor level, 21 apartments were located at the fourth-equivalent-floor level and 10 apartments were located at the fifth-equivalent-floor level.

The measurements and findings showed that the overall weighted average of the CWL in the sample was 7.69 liters.

The average CWL at the first equivalent-floor level was 6.15 liters, while the average CWL was 6.88 liters at the second equivalent-floor level, and at the third equivalent-floor level it was found that the average CWL is 8.7 liters. At the fourth equivalent-floor level, the average CWL was 10.1 and finally, at the fifth equivalent-floor level the average CWL was also 10.1.

The survey considered many other variables and measurements. The following items show a summary of these findings:

- **Water Losses According to the System Pumping (Forced System or Thermo siphon)**

The survey showed that only 16 households (10% of the sample) had installed a forced pumping system while 139 households (90% of the sample) had installed a thermo siphon pumping system. The measurements showed that the average CWL for the forced pumping system was 4.8 liters while it was 8.2 liters for the thermo siphon pumping system.

- **Water Losses According to the System Type (Vacuum System or Flat Plate)**

The site visits revealed that 52% of the visited households had installed a vacuum solar water-heating system (evacuated tubes) and 48% of the sample had installed a flat plate system. The average CWL measured for the vacuum system was 7.2 liters, while it was 8.1 liters for the flat plate system.

- **Water Losses According to the System Insulation (Insulated Systems or Non-Insulated Systems).**

The survey showed that only 23 households (15% of the sample) have an insulation layer over the hot water pipes, while 1**32** households (85% of the sample) were don't have it. The average CWL for the insulated systems was 8.4 liters while it was 7.6 liters for the non-insulated systems. The higher number of CWL for the insulated systems is due to the higher equivalent-floor level, more details and analysis could be found in Chapter 3, Detailed Analysis.

- **Water Losses According to the System Age**

It was found that the CWL increase proportionally with the system aging. The average CWL for systems less than 15 years old was 7.2 to 7.4 liters, while in systems with an age of more than 15 years the average CWL was 11.8 liters.

- **Water Losses According to the Geographical Area:**

The study found that, in this case, CWL is not related to geographical area. The findings showed that the average CWL for the households of east Amman was 7.4 liters, while the CWL in west Amman is 7.7 liters

- **Total Water Losses for Families According to Their Weekly Number of Showers and Their Equivalent-Floor Level**

The average family size for the sample was 5.3. The measurement and findings showed that the average CWL for families who live at the first equivalent-floor level is 197 liters per week, while it was 186 liters per week for families who live at the second equivalent-floor level; and for families who live at the third equivalent-floor level, the average weekly CWL was 289 liters. Families who live at the fourth equivalent-floor level have a weekly CWL of 315 liters and families who live at the fifth equivalent-floor level the average weekly CWL was 330 liters. It's worth mentioning that the above figures are during the summer time which extends from April to October in Jordan.

- **Average Cost of Solar Water Heaters According to Their Type (Vacuum System or Flat Plate)**

It was found that the average cost of the vacuum solar water-heating system is JD546, while the average cost of the flat plate system is JD474. Cost of system did not equate significantly with efficiency.

- **Method of Water Heating as a Backup to the Solar water-heating system**

The survey showed that 51% of the sample uses diesel boilers for water heating as a back up to the solar water heater, 34% of the sample uses electrical heaters and 15% use LPG boiler

- **Customer Satisfaction**

Among the visited sample, only 4% were unsatisfied with the solar water-heating system, 17% said their system is good and there are no problems with the system, 79% said their system is excellent and they would recommend similar systems to their relatives and friends.

- **Customers Who Did Research Before Buying the Solar Water Heaters**

The survey showed that only 15% of the sample had done research and market visits before buying their solar water-heating system. On the other hand, the majority (85% of the sample) had done no research and had installed their system based on a recommendation from their friends or relatives.

- **The Distribution of the Solar Water Heaters based on the System Origin.**

The majority of the solar water heaters were manufactured in China, representing about 40% of the households. Jordanian heaters comprised 35% of the heaters. Japanese systems were 10% and Turkey and Germany each accounted for 1%. The surveyors were unable to identify the origin for 13% of the sample.

To mitigate the CWL from the solar water-heating systems before the hot water reaches the end user, the following recommendations need to be considered. It should be mentioned here that the recommendations will not only reduce the CWL but also will reduce the thermal energy losses that occur when cold water backs into the solar water-heating system:

1. Install a circulation pump for the hot water.
2. Properly select the solar water-heating system's location, pipe size and the hot water pipes' path.
3. Install a high-efficiency insulation layer.
4. Building capacity for vocational training programs for technicians in the SWH and plumbing industry
5. Building capacity for engineering training programs for engineers who design and supervise implementation of plumbing works
6. Enforcement of codes:
    a. Create penalty schemes for improper installations
    b. Establish auditing committees that make random checking on constructions
    c. Give these committees incentives in order to motivate them

EXECUTIVE SUMMARY (ARABIC) الخلاصة

يهدف هذا التقرير الى تسليط الضوء على كميات المياه الباردة المهدورة من الانظمة الشمسية قبل وصول الماء الساخن للمستخدم النهائي لمختلف المنازل السكنية في عمان . لهذا الغرض فقد تمت دراسة عينة ميدانية من سكان المنازل في مدينة عمان و بعدد اجمالي 155 منزلا يمتلكون نظاما لتسخين المياه بالطاقة الشمسية لقياس الفواقد في المياه الباردة عند ابعد نقطة استحمام عن النظام الشمسي.

لقد تم اجراء الدراسة الميدانية و مرحلة التقييم و جمع المعلومات عن طريق فريقي عمل مختصين، كل فريق يعمل تحت اشراف مهندس مختص و يسانده فني تمديدات ذو خبرة و دراية في انظمة السخانات الشمسية بالاضافة الى مساعدة ادارية ، حيث قامت الفرق الميدانية بجمع العديد من المعلومات لتقييم حالة السخان الشمسي و اجراء الدراسات اللازمة لكميات المياه الباردة المهدورة من النظام ، نوجز فيما يلي بعض المعلومات الرئيسية التي تم جمعها خلال الدراسة الميدانية:

- عدد الطوابق في المبنى و مستوى الطابق المخدوم بالنظام الشمسي.
- المسافة الواقعة بين النظام الشمسي و ابعد شور للاستحمام.
- قياس كميات المياه المهدورة من النظام الشمسي قبل وصول المياه الساخنة.
- عدد افراد الاسرة و عدد تكرار مرات الاستحمام اسبوعيا.

تناولت الدراسة 58 منزلا في مستوى الطابق المكافئ الاول ، بينما 33 منزلا كانت في مستوى الطابق المكافئ الثاني ، 33 منزلا كانت في مستوى الطابق المكافئ الثالث ، 21 منزلا كانت في مستوى الطابق المكافئ الرابع بينما كان عدد المنازل الواقعة في الطابق المكافئ الخامس 10 منازل. و المقصود هنا بالطابق المكافيء هو عدد الطوابق التي تقع بين النظام الشمسي و الشقة المخدومة بالنظام و ليس مستوى الطابق في المبنى.

لقد اظهرت القياسات و التحاليل التي تم جمعها من المنازل بان كميات المياه الباردة المهدورة من الانظمة الشمسية تصل بالمعدل العام الى حوالي 7.69 لتراً قبل وصول المياه الساخنة الى المستخدم النهائي ، حيث اظهرت القياسات ان معدل الفاقد في المياه الباردة يصل الى 6.15 لتراً في المنازل الواقعة في مستوى الطابق المكافئ الاول ، بينما كان الفاقد في المياه الباردة للمنازل الواقعة في مستوى الطابق المكافئ الثاني 6.88 لتراً ، اما في مستوى الطابق المكافئ الثالث فقد كان الفاقد 8.7 لتراً ، و للمنازل الواقعة في مستوى الطابق المكافئ الرابع كان 10.1 لتراً و بالنسبة للمنازل الواقعة في مستوى الطابق المكافئ الخامس فقد كان 11 لتراً.

لقد تناولت الدراسة الميدانية العديد من العوامل الاخرى التي تلعب دورا مباشراً او غير مباشراً في كميات المياه المهدورة ، حيث نوجز فيما يلي نتائج التحاليل الخاصة بهذه العوامل :

- **كميات الفاقد في المياه حسب نوع نظام ضخ المياه الساخنة من السخان الى الشقة (ضخ انسيابي ام ضخ بواسطة مضخة ميكانيكية)**

لقد اظهرت الدراسة وجود 16 منزلا (10% من العينة) تمتلك نظام ضخ للمياه الساخنة بواسطة مضخة تدوير مقارنة مع 139 منزلا (90% من العينة) تمتلك نظاما انسيابيا لضخ المياه الساخنة . اشارت نتائج القياسات الى ان معدل الفاقد في المياه الباردة في المنازل التي تمتلك نظام ضخ يعمل بواسطة مضخة تدوير يصل الى 4.8 لتر بينما يصل الى 8.2 لتر في الانظمة التي تعتمد نظاما انسيابيا لضخ المياه الساخنة.

- **كميات الفاقد في المياه حسب نوع نظام السخان الشمسي (انابيب مفرغة ام الواح مسطحة):**

اشارت نتائج الدراسة الميدانية الى ان حوالي 52% من عدد المنازل تستخدم انظمة سخانات شمسية تعمل بتكنولوجيا الانابيب المفرغة بينما حوالي 48% وجدت تستخدم تكنولوجيا الالواح المسطحة. كما اظهرت نتائج التحاليل و القياسات بان معدل الفاقد في المياه الباردة في المنازل التي تمتلك نظام الانابيب المفرغة يصل بالمعدل الى 7.2 لتر بينما يصل الى 8.1 في السخانات التي تعمل بتكنولوجيا الالواح المسطحة .

- **كميات الفاقد في المياه بالنسبة للعزل الحراري للنظام الشمسي (انابيب النظام الشمسي معزولة ام غير معزولة):**

لقد اظهرت الدراسة وجود 23 منزلا (15% من العينة) لديها نوع من انظمة العزل لخطوط المياه الساخنة بينما 132 منزلا (85% من اجمالي العينة) فلم يتم ملاحظة اي نوع من انواع العزل على خطوط المياه الساخنة . كما اشارت نتائج القياسات الى ان معدل الفاقد في المياه الباردة في المنازل التي تمتلك انابيا معزولة للمياه الساخنة حوالي 8.4 لتر بينما يصل الى 7.6 في الانظمة الغير معزولة . ان الفاقد في المياه الباردة للانظمة المعزولة قد وجد اعلى منه للانظمة الغير معزولة بسبب بعد الانظمة الشمسية عن مستوى الشقة ، مزيد من التحاليل بهذا الخصوص مدرجة في الجزء الثالث من هذا التقرير (DETAILED ANALYSIS).

- **كميات الفاقد في المياه حسب عمر النظام الشمسي:**

اظهرت الدراسة بان كميات المياه الباردة المفقودة من الانظمة الشمسية تزداد طرديا بزيادة عمر النظام حيث قد وجد ان معدل الفاقد في المياه الباردة يترواح ما بين 7.2 و 7.4 لتر للسخانات ذات العمر اقل من 15 سنة بينما وجد الفاقد في المياه الباردة حوالي 11.8 لتر للسخات ذات العمر الاعلى من 15 سنة.

- **كميات الفاقد في المياه حسب المنطقة الجغرافية داخل مدينة عمان:**

بالرغم من عدم تأثر الفاقد في كميات المياه الباردة بالموقع الجغرافي للسخان في هذه الحالة فقد اظهرت النتائج بان معدل الفاقد في المياه الباردة في مناطق عمان الشرقية يصل الى 7.4 لتر اما في مناطق عمان الغربية فقد وجد الفاقد في المياه الباردة حوالي 7.7 لتر.

- **كميات الفاقد في المياه للعائلات حسب معدل عدد مرات الاستحمام الاسبوع صيفا و حسب عدد الطوابق المكافئة:**

اظهرت الدراسة بان معدل عدد افراد الاسرة يتراوح ما بين 4.4 الى 5.5 ، اما القياسات فقد اظهرت بان معدل الفاقد الاسبوعي في المياه الباردة للعائلات التي تقطن في مستوى الطابق المكافئ الاول قد كان 197 لتر ، اما بالنسبة للعائلات التي تقطن في مستوى الطابق المكافئ الثاني فقد كان الفاقد الاسبوعي بحدود 186 لتر ، و بالنسبة للعائلات التي تقطن في مستوى الطابق المكافئ الثالث فقد وجد الفاقد الاسبوعي بحدود 289 لتر ، بينما للعائلات التي تقطن في مستوى الطابق المكافئ الرابع فقد كان الفاقد الاسبوعي بحدود 315 لتر و اخيرا بالنسبة للعائلات التي تقطن في مستوى الطابق المكافئ الخامس فقد كان الفاقد الاسبوعي حوالي 330 لتر. و من الجدير ذكره ان الارقام المدرجة اعلاه قد تم اخذها بعين الاعتبار خلال فترة الصيف التي تبدا في بداية شهر نيسان و تنتهي مع نهاية شهر تشرين الاول من كل عام.

- **معدل سعر نظام السخان الشمسي حسب تكنولوجيا النظام (انابيب مفرغة ام الواح مسطحة)**

لقد اظهرت نتائج الدراسة بان معدل سعر نظام السخان الشمسي الذي يعمل بتكنولوجيا الانابيب المفرغة يصل الى 546 دينار اردنيا بينما الانظمة التي تعمل بتكنولوجيا الالواح المسطحة يصل بالمعدل الى 474 دينار اردنيا.

- **طرق تسخين المياه كنظام مساعد للسخان الشمسي**

اظهرت النتائج بان حوالي 51% من اصحاب المنازل يستخدمون بويلر الديزل كنظام مساعد ، بينما حوالي 35% من العينة وجدت تستخدم السخان الكهربائي و اخيرا حوالي 15% من العينة تستخدم سخان المياه الذي يعمل على الغاز.

- **رضى المستهلكين (اصحاب المنازل) عن اداء السخان الشمسي:**

وجدت الدراسة بان حوالي 4% من اصحاب المنازل غير راضين عن اداء النظام الشمسي العائد لهم ، بينما اشار حوالي 17% من العينة الى ان النظام العائد لهم يعمل بشكل جيد و بدون مشاكل ، اما الغالبية العظمى من اصحاب المنازل (حوالي 79%) فقد وجدت راضية تماما عن اداء السخان الشمسي و هم يقومون بتادية النصح و الارشاد لاقاربهم و اصدقائهم لتركيب نفس النوعية من السخانات.

- **مالكي السخانات التي قاموا باجراء بحث و دراسة لمعرفة انواع السخانات الشمسية و مزاياها قبل الشراء:**

اظهرت نتائج الدراسة بان الغالبية العظمى من المنازل (حوالي 85%) لا تقوم بعمل اي بحث في الاسواق لمعرفة الانواع المتوافرة و مزاياها للمقارنة بينها و اختيار الانسب حيث قاموا بشراء السخان بعد توصية من احد الاقارب او الاصدقاء ، بينما اشار 15% فقط من العينة الى قيامهم بعمل دراسة للسوق و المنتجات المتوافرة فيه و اسعارها و مواصفاتها لاختيار الانسب منها.

- **توزيع انظمة السخانات الشمسية حسب بلد المنشأ:**

اظهرت الدراسة بان معظم السخانات الشمسية المستخدمة (حوالي 40% من العينة) ذات منشا صيني متبوعة بالسخانات محلية الصنع و بنسبة 35% ، اما السخانات ذات المنشا الياباني فقد وجدت بنسبة انتشار وصل الى 10% و نسبة ضءيلة من السخانات ذات المنشا التركي و الالماني بنسبة انتشار 1% لكل منهما. بالمقابل فقد وجدت بعض السخانات ذات الجودة المتدنية او القديمة منها بدون اسم للشركة المصنعة للنظام بحيث لم يكن بالامكان التعرف على بلد المنشأ اضافة الى عدم معرفة مالك السخان بمنشاه.

لتخفيض معدل الفاقد في المياه الباردة الذي يتم هدره قبل وصول المياه الساخنة للمستخد النهائي فقد اوصت الدراسة باتباع التوصيات التالية التي من شانها تخفيض الفواقد في المياه الباردة بالاضافة الى تخفيض تخفيض الفاقد الحراري الذي يحصل عن تعويض مياه السخان بمياه باردة:

1. تركيب مضخة تدوير ميكانيكية على خطوط المياه الساخنة.
2. الاختيار الامثل لموقع السخان الشمسي ، قطر خط المياه الساخنة المستخدم و مسارات خطوط المياه الساخنة.
3. عزل انابيب المياه الساخنة باحد العوازل الحرارية ذات الكفاءة العالية.
4. عمل برامج تدريبية مهنية لفنيي تمديدات السخانات الشمسية.
5. عمل برامج تدريبية هندسية لمهندسي التصميم و التنفيذ.
6. إلزامية تنفيذ الكودات:
   - فرض عقوبات على المخالفين لكودات البناء الوطني فيما يتعلق بالسخانات الشمسية.
   - تأسيس فرق عمل لمراقبة المباني عشوائياً.
   - خلق حوافز لهذه الفرق لتشجيعها على العمل بشفافية.

1.0 INTRODUCTION

1.1 Project Background and Objectives

Using the sun's energy to heat water is not a new idea. More than one hundred years ago, water tanks were painted black and used as simple solar water heaters in a number of countries. Solar water-heating (SWH) technology has greatly improved during the past century. Today there are more than 30 million square meters of solar collectors installed around the world.

Solar water heaters have been used in Jordan since 1972. Since that time, there has been widespread use of solar water heaters in Jordan. Currently, 14%[1] of Jordanians have solar water heaters installed at their place of residency.

Previous feasibility studies showed that SWH technology, if compared to the other available technologies, is the most economically feasible way to heat water, with a payback period of just 3-4 years.

At the same time, the adoption of solar water heaters in Jordan's various sectors faces some challenges face, such as the initial cost and the long distances between the solar collector and the end user.

A common operational problem related to solar water heaters is the amount of cold-water losses (CWL) before hot water can reach household water fixtures such as showerheads, kitchen sinks and the bathroom faucets. This problem is well known and extensive in Jordan. Many users of solar water heaters have expressed their dissatisfaction of such systems due to the considerable amount of lost cold water.

To gain a better understanding of the complexity of this problem and to obtain more detailed figures about the cold-water losses, the Public Action for Water, Energy and Environment Project contracted with Eco Engineering and Energy Solutions (EcoSol) to conduct a field assessment of domestic solar water heaters. The objectives of this assessment are:

1. Calculate and measure the cold-water losses due to solar water heaters on the household level according to the variables that affect the cold-water losses.

2. Conduct a situational analysis on the use and status of the solar water heaters from the customer point of view.

3. Propose applicable solutions to overcome the cold-water losses in Jordan.

The problem analysis has considered all the variables that affect cold-water losses directly or indirectly. This report shows the measurements, analysis and results.

[1] PAP Household survey 2010, and Department of Statistics 2011

1.2 Research Methodology

The methodology developed for this field assessment of domestic solar water heaters is driven by the main objectives mentioned earlier in this report.

The adopted methodology meets the objectives by employing a combination of tools and an analytical approach. A scenario-based approach was used to examine a set of variables on the household level, and then identify and analyze the problems.

To do this, a representative sample of 155 residential units was visited by the EcoSol team in order to evaluate the installed solar water-heating systems and to measure the cold-water losses.

The field survey was conducted by two teams. Each of them consists of one engineer as a team leader, one plumber and one female assistant. The main variables obtained through the site visits were the following:

- The residential apartment floor level and the total floors in the building.
- The geographical location of the households.
- The distance between the solar water-heating system and the most distant showerhead.
- The cold-water losses displaced by the system before the hot water become available.
- Family size and the weekly average number of showers.
- Solar water-heating system's pumping type (whether forced solar water-heating system or thermosiphon)
- Solar water-heating system's technology (whether vacuum system or flat plate)
- Solar water-heating system supplier and the brand origin.
- Solar water-heating system cost
- Solar water-heating system age
- Pipe insulation
- Method of water heating before installing the solar water-heating system
- The adopted method of buying the solar water-heating system (whether by a recommendation or browsing the market)
- Customer satisfaction

The households were carefully selected by the technical team to ensure reasonable diversity in terms of the following criteria:

- Apartment floor level
- System technology
- Geographical locations

For each one of the visited households, the field teams used the following process to facilitate the process and to override resistance from the households:

1. Initial contact was made by the female assistant to explain the assessment targets and to get approval from the households.
2. Second contact to set an appointment (1 or 2 hours before the visit)
3. Visiting the households and measuring the CWL
4. Filling the visit questionnaire

5. Onsite evaluation of the solar water heater and the technical aspects related to the solar water heater.

At the end of each day during the field assessment study, all the filled questionnaires were compiled into a system data base for the purpose of the analysis.

The analysis took into consideration many factors which affect the CWL at the household level and sought viable solutions to help reduce the amount of displaced cold water.

2.0 KEY FINDINGS

This chapter addresses the key findings of the project which are presented in more details in Chapter 3. The key findings presented were developed based on the thorough site survey conducted by the technical teams in the 155 households in Amman.

The houses were classified based on the equivalent-floor level. Accordingly the survey technical teams visited 58 house (37% out of the total sample) on the first equivalent-floor level, 33 house (21% out of the total sample) on the second equivalent-floor level , 33 house (21% out of the total sample) on the third equivalent-floor level, 21 houses (14% out of the total sample) on the fourth equivalent-floor level and 10 houses (7% out of the visited sample) on the fifth equivalent-floor level.

The overall weighted average of the CWL in the visited sample was 7.69 liters, the below table shows the average of the measured water losses at each equivalent-floor level:

Table 1: The Average of the Measured CWL at Each Equivalent-floor Level

Equivalent-floor Level	Average Measured CWL (lit)	Min (lit)	Max (lit)	Standard Deviation
1	6.15	2	20	3.52
2	6.88	3	13	2.51
3	8.7	5	24	3.9
4	10.1	4	23	4.1
5	11	8	14	2.3

The following points illustrate the key findings of the survey:

1. The average CWL for the forced pumping system was **4.8 liters**, while it was **8.2 liters** for the thermosiphon pumping system.

2. The average CWL for the vacuum system was **7.2 liters**, while in the flat plate system the average CWL was found to be **8.1 liters**.

3. The average CWL for insulated hot water pipes was **8.4 liters**, while for the non-insulated systems it was **7.6 liters.** It's worth mentioning that the higher losses in the insulated systems is due to its higher equivalent-floor level which was found to be 2.7 floors while it was 2.2 floors for the solar water-heating systems, which was not insulated.

4. The average CWL is about **7.2 to 7.4 liters** for systems installed less than 15 years ago. On the other hand, the systems that were installed more than 15 years ago, the measurements showed that the CWL is about **11.8 liters.**

5. The average CWL for the households of east Amman was **7.4 liters** while the CWL of west Amman is **7.7 liters.**
6. The table below shows the average family size based on the equivalent-floor level of their apartment and the CWL losses

Table 2: Average Family Size and the Cold-water losses

Equivalent-floor Level	Average Family Size	Weekly Average Number of Showers	Average CWL (liters)	Total CWL Per week (liters)
1	5.4	2.29	6.1	197
2	4.7	2.17	6.8	186
3	5.4	2.34	8.7	289
4	4.4	2.8	10.1	315
5	5.5	1.3	11	330

7. The average cost of the vacuum solar water-heating system is JD546, while the average cost of the flat plate system is JD474.

8. The survey showed that 51% use diesel boilers for water heating as a back up to the solar water-heating system, 34% use electrical heaters and 15% use LPG boiler.

9. Of the sample, 4% said they are not satisfied by the solar water-heating system due to the system's low efficiency, high cold-water losses, water leaks and/or the capacity of the system. Meanwhile, 17% said their system is good and there are no problems, but they feel that there are other systems in the market better than theirs. A majority, 79%, said their system is excellent and they would recommend similar systems to their relatives and friends.

10. The results showed that only 15% of the sample did research and market visits before buying their solar water-heating system. The majority, 85% of the sample, didn't do any research and installed their system based on a recommendation from their friends or relatives.

11. The survey and analysis showed that the majority of the solar water heaters were manufactured in China representing about 40% of the visited sample. Jordan followed at 35%, then Japanese systems with 10% and Turkey and Germany each had 1% share of the sample. The remaining 13% of the sample were very old and the origins weren't identified.

3.0 DETAILED ANALYSIS

This section addresses in more details the solar water-heating systems field study findings and analysis of those findings. The analysis was developed based on the thorough site survey conducted by the two technical teams when they visited 155 households in Amman in order to evaluate the installed solar water-heating systems and to measure the cold-water losses.

The collected data from the households was filed into a questionnaire, and then complied into a database for analysis purposes. The following data points were collected from the households:

- Customer name and his/her contact details
- Address of the house and the geographical area
- Type of dwelling unit (apartment, villa or separate house)
- The residential apartment floor level and the total floors in the building
- The distance between the solar water-heating system and the most distant showerhead
- Family size and the average showers per week for the family members
- The cold-water losses displaced by the system before the hot water become available
- The solar water-heating system type (vacuum system or flat plate)
- Solar water-heating system pumping technology (forced system or thermosiphon)
- Cost and age of the solar water-heating system
- The pipe size used to convey the hot water to the apartment
- Hot water pipe insulation (insulated or non insulated)
- The method of water heating as a backup to the solar water-heating system
- Customer satisfaction

The following sections provide a detailed description of the study analysis and the findings, as well as our comments.

3.1 The Visited Households and the Breakdown of the Visited Sample Classified According to Their Equivalent-Floor Level

For the purpose of this analysis, the equivalent-floor level terminology has been used instead of the apartment floor level. The equivalent-floor level is defined as the total number of floor-falls between the solar water-heating system and the apartment.

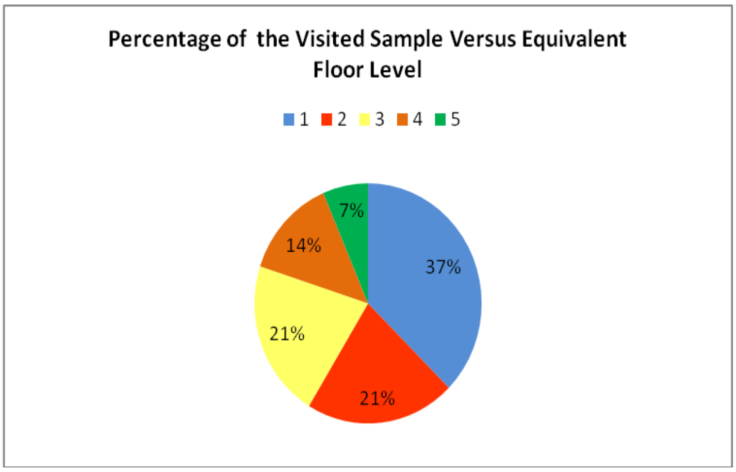
This table shows the visited sample and the breakdown of this sample based on the equivalent-floor level.

Table 3: Breakdown of the Visited Residential Sample Based on the Equivalent-floor Level

Equivalent-floor Level	Number of visited Houses
1	58
2	33
3	33
4	21
5	10

The below figure illustrates the percentage of the visited sample versus equivalent-floor level.

Figure 1: breakdown of the visited residential sample based on the equivalent-floor level



From the above mentioned table and figures, it could be noticed that 37% of the sample has an equivalent-floor level equals to 1 , the households falls under this category are those who lives in the last floor of the building and who lives in a separate dwelling unit and villas, which the solar water-heating system is installed directly above their roofs.

21% of the sample has an equivalent-floor level of 2, the households falls under this category are those who lives in a building and there are only one floor above them.

21% of the sample has an equivalent-floor level of 3, the households falls under this category are those who lives in a building and there are two floors above them.

14% of the sample has an equivalent-floor level of 4, the households falls under this category are those who lives in a building and there are three floors above them.

And 7% of the sample has an equivalent-floor level of 5, the households falls under this category are those who lives in a building and there are four floors above them.

3.2 The Measured Cold-water losses According to the Equivalent-floor Level

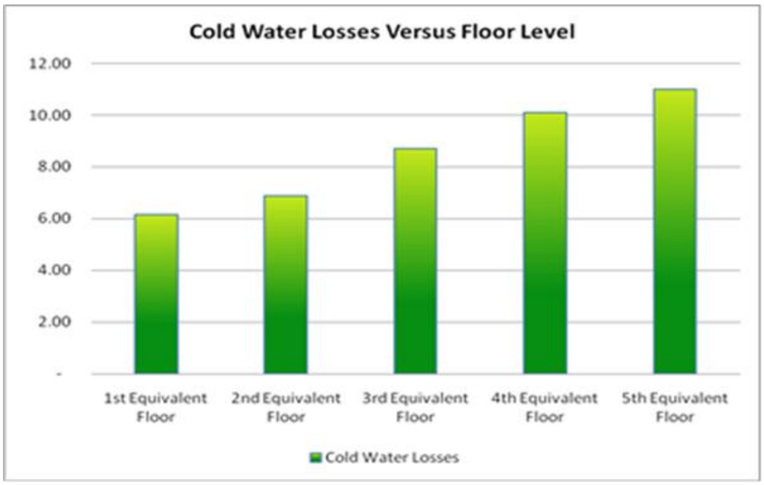
The cold-water losses were measured by the team using a special flask at each visited dwelling unit. The measurements showed that the overall average of the CWL in the sample was 7.69 liters, the below table shows the average of the measured water losses at each equivalent-floor level.

Table 4: the Average of the measured CWL at each equivalent-floor level

Equivalent-floor Level	Average Measured CWL (lit)	Min (lit)	Max (lit)	Standard Deviation
1	6.15	2	20	3.52
2	6.88	3	13	2.51
3	8.7	5	24	3.9
4	10.1	4	23	4.1
5	11	8	14	2.3

The next figure illustrates the CWL versus equivalent-floor level graphically.

Figure 2: Measured CWL versus Equivalent-floor Level



Feedback and Comments:

From the above figures and table, it should be noticed that the CWL before the hot water reaches the showerhead increases proportionally to the equivalent-floor level, which is mainly due to the increase in the total distance between the solar water-heating system and the most distant shower head.

The minimum measured CWL was two liters, which was found for those apartments who have an equivalent-floor level of one. The maximum CWL was 24 liters. This high figure was investigated by the specialized engineers and the plumbers, who found it was caused by an exaggerated loop in the hot water pipes. The pipes followed the easiest path, not the shortest, to the apartment, with no regard for pipe length. The reason for this was due to one of the following reasons:

- The presence of obstacles (walls, water tanks, scrap) during the installation of the solar water-heating system which made it harder for the technicians to install the solar water-heating system following the shortest path. Therefore, the installation of the hot water pipes took longer routes.

- Poor placement of the solar water-heating system on the roof, putting it in the farthest possible location.

3.3 Cold-Water Losses According to the System Pumping

The site visits revealed that only 16 customers out of 155 had installed a forced pumping system on their solar water-heating system. The average CWL for those who installed the forced pumping system was 4.8 liters, while for those who installed a thermosiphon pumping system the CWL was found to be 8.2 liters.

Figure 3: Percentage of Forced Solar Water-Heating Systems Vs. Thermosiphon Solar Water-Heating Systems

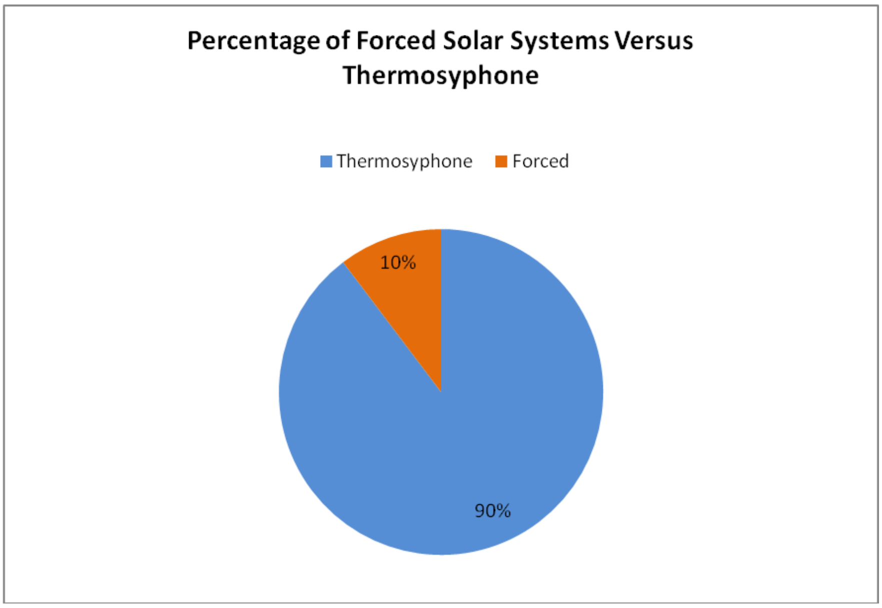
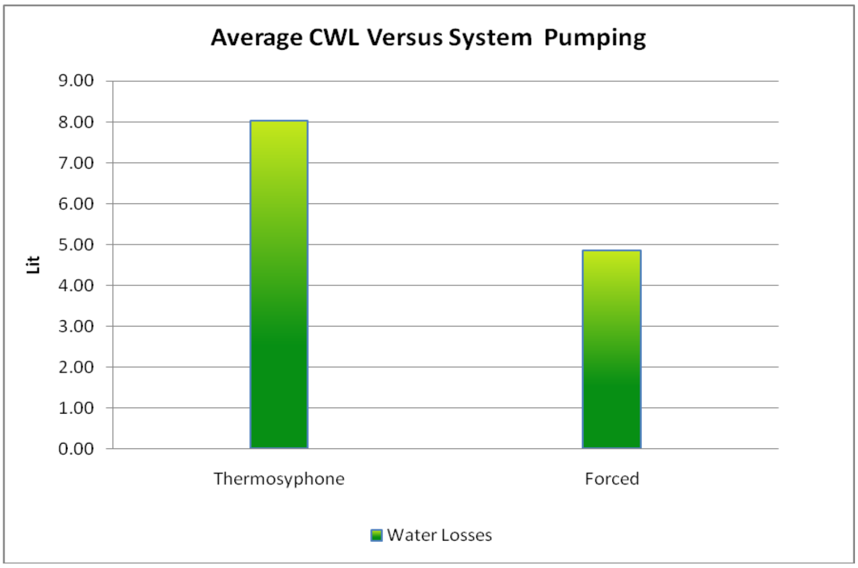


Figure 4: Average Cold-Water Losses Vs. System Pumping



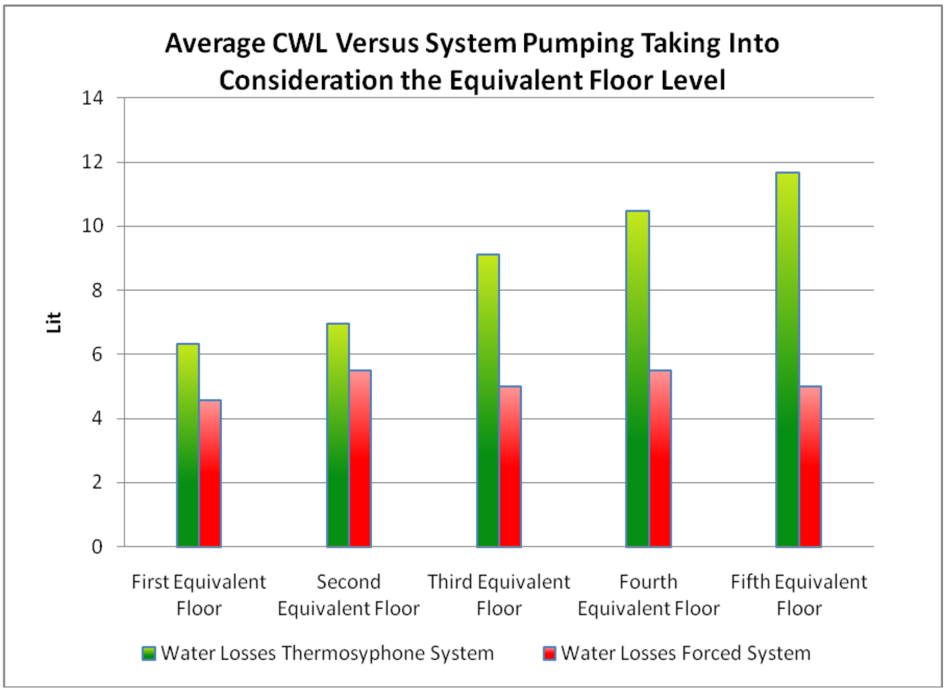
Feedback and comments:

The teams found that households who installed the forced system pumping have an the equivalent-floor level of 1.9, while those who had installed the thermosiphon pumping system were located at an equivalent-floor level of 2.35

The limited number of customers who had installed the forced systems is due to its higher cost. Installation of forced systems in apartments with high equivalent-floor levels is being offered to some customers who have low hot water pressure. This is not done as a water-saving measure, but to increase customer satisfatction with their hot water pressure.

This figure shows the CWL as a comparison between the forced systems and the thermosiphon for the same equivalent-floor level.

Figure 5: Average Cold-Water Losses Vs System Pumping Taking Into Consideration the Equivalent-Floor Level

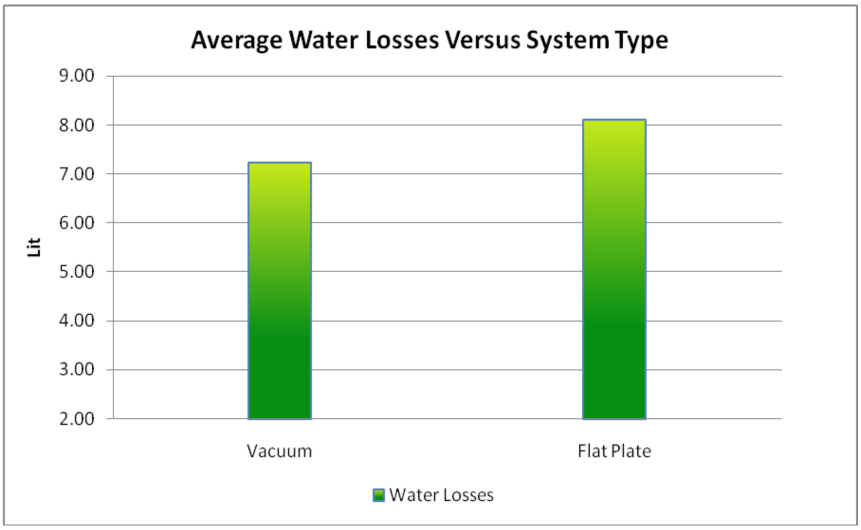


From the above figure, the positive effect of the forced system on cold-water losses is very clear.

3.4 Water Losses According to the System Type (Vacuum System or Flat Plate)

The site visits revealed that 52% of the households had installed a vacuum solar water-heating system (evacuated tubes) and 48% of the sample had installed a flat plate system. The average CWL measured for customers who had a vacuum system was 7.2 liters, while those with a flat plate system averaged CWL of 8.1 liters.

Figure 6: Average Cold-water losses Vs System Type



Feedback and Comments:

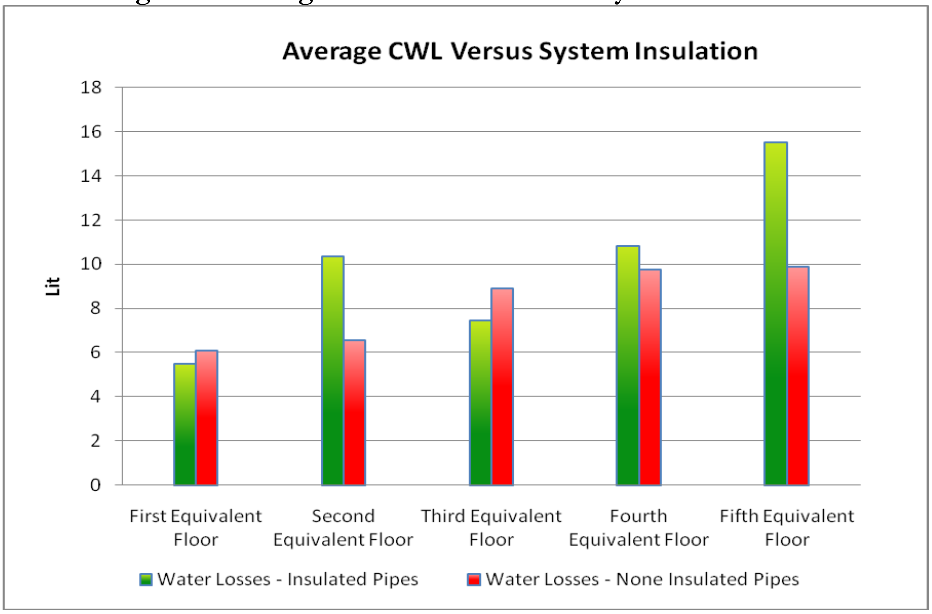
Those who installed the vacuum system are located at an average equivalent-floor level of 2.4, while those who with the flat plate system were located at an average equivalent-floor level of 2.2.

In fact, the system type (whether vacuum solar water-heating system or flat plate solar water-heating system) does not have any impact on the CWL losses. The loss of water depends mainly on other variables, such as the equivalent-floor level, system pumping and system insulation.

3.5 Water Losses According to the System Insulation (Insulated Systems or Non-Insulated Systems)

The site visits showed that only 15% of the households have insulation over the hot water pipes, while 85% have none (either it wasn't installed or was damaged due to aging). The average CWL measured for customers with insulation over the solar water-heating system pipes was 8.4 liters, while those without had CWL of 7.6 liters. However, comparing the CWL should be carried out for each equivalent-floor level to extract the losses for insulated and non-insulated systems, which is shown below.

Figure 7: Average Cold-water losses Vs System Insulation



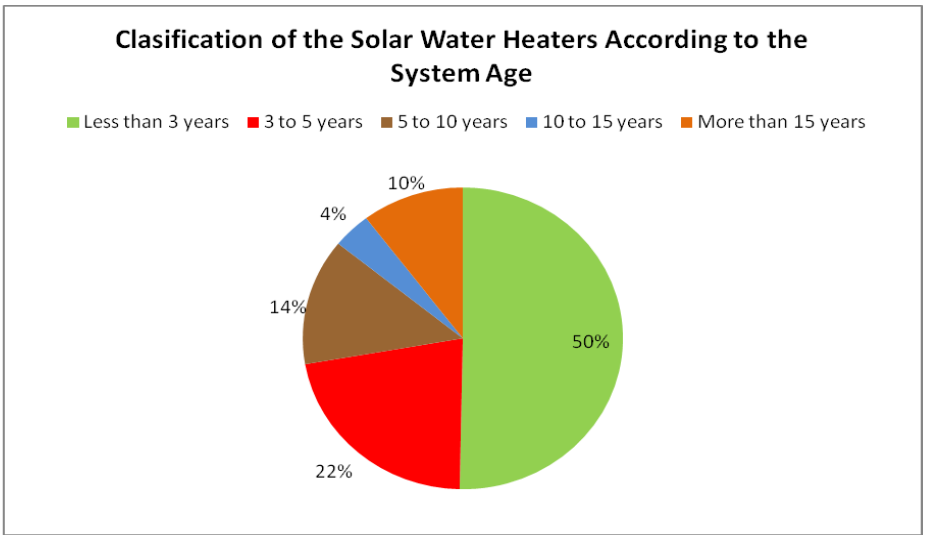
Feedback and Comments:

From the above figure, it should be noticed that insulated pipes have higher average water losses higher than the non-insulated pipes, especially for the second and the fifth equivalent floors. This result is considered unrepresentative due to the limited number of insulated systems. It is strongly believed that the insulation layer reduces the thermal losses and maintains the hot water in the pipes for longer period of time than the non insulated pipes.

3.6 Water Losses According to the System Age.

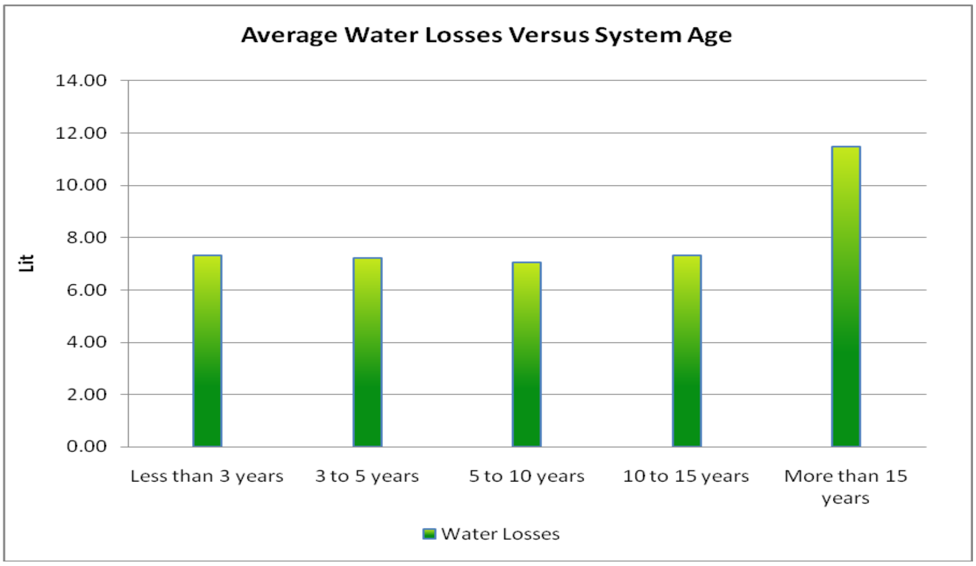
The age of the solar water heaters play a major role in its effectiveness and efficiency. The site visits showed that the solar water heaters have been used since more than 30 years in Jordan. The below figure illustrates the distribution of the sample classified according to the system age.

Figure 8: Classification of the Solar Water Heaters According to the System Age



The figure below illustrates the measured CWL for those customers classified based on the system age.

Figure 9: Average Cold-water losses Vs System Age



Feedback and Comments:

The average CWL is about 7.2 to 7.4 liters for systems were installed less than 15 years ago. The very old systems, which were installed since more than 15 years ago, had CWL of 11.8 liters. The equivalent-floor level of the new and old system is close, ranging between just 2.2 to 2.6.

The old solar water-heating systems were evaluated by the plumbers during the site visits. The evaluation and investigation showed that the old solar water heaters supply hot water using galvanized steel pipes. Galvanized steel pipes are considered an old technology in the plumbing industry and do not provide flexibility in utilizing the shortest routes from system to water fixtures. The effect of these pipes and extra lengths is very clear on the amount of CWL, which was 55% higher than polyethylene pipes, which are flexible, more reliable and have a lower thermal loss.

3.7 Water Losses According to the Geographical Areas.

This study considers the geographical area of the households, specifically the neighborhood and side of Amman (east or west). Although there is no clear official definition for east or west Amman, the following table shows the areas which were classified under those two geographical areas.

Table 5: Classification of Amman Areas (East or West).

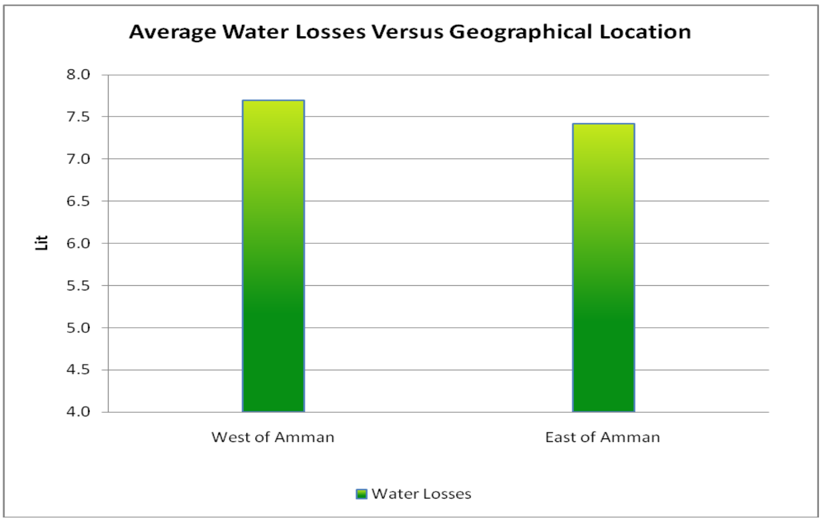
East Amman	West Amman	
Tabarbour	Swelieh	Daheyet Al-Rasheed
Sport City	Tla' Al-Ali	Al-Sarew
Daheyet Al Aqsa	Al-Jandaweel	Dayehet Al-Sadeq
Al-Hashemy Al-Shamaly	Daheyet Al-Rawdah	Daheyet Al-Farouq
Al - Ourdon Street	Marj Al-Hamam	Abu Nsier
Jabal Al-Ashrafeyeh	Abdoun	Deir Ghbar
Daheyet Al-Amir Hasan	Swifeyeh	Shmesani
	Khilda	Gardens Street
	Daheyet Al-Rasheed	Wadi Saqra
	Shifa badran	Al-Rabyeh
	Al-Jubaiha	Um - Alsommaq
	Mecca Street	

The penetration of solar water heaters in west Amman is higher than in east Amman. The field surveyors visited 25 households (about 16% of the total sample) in east Amman and 130 households (about 84% of the total sample) in west Amman.

Customers who lives in east Amman have, in general, lower annual incomes compared to customers who live in the west Amman, which helps explain the higher penetration of solar water-heating systems in the western portion of the city.

The findings show the average CWL for the households in east Amman is 7.4 liters, with an equivalent-floor level of 2.19. In west Amman, CWL is 7.7 liters and the equivalent-floor level is 2.3.

Figure 10: Average Cold-water losses Vs Geographical Location



Feedback and Comments:

It is strongly believed that the geographical area or the physical location of the solar water heaters does not play any role in the CWL if the same systems are installed within the same climate area.

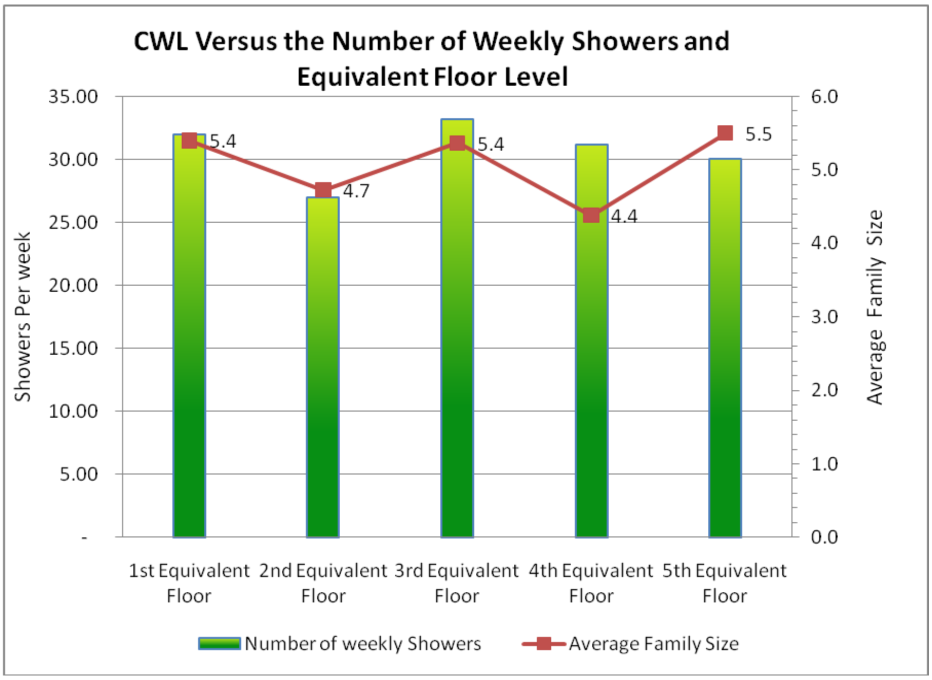
3.8 Water Losses for Families According to Their Weekly Number of Showers and Their Equivalent Floor.

The survey considered the total weekly CWL during summer based on family size and the weekly number of showers. Some families said they took showers once a day, while others said showered twice per day. The table bekow shows the average family size at the equivalent-floor level and the CWL.

Table 6: Family Size and the Cold-water losses

Equivalent-floor level	Average Family Size	Weekly Average Number of Showers	Average CWL (liter)	Total CWL Per Week (liter)
1	5.4	32	6.1	197
2	4.7	26.9	6.8	186
3	5.4	33.2	8.7	289
4	4.4	31.2	10.1	315
5	5.5	30	11	330

Figure 11: Average Cold-Water Losses Vs. Weekly Number of Showers and Equivalent-Floor level



Feedback and Comments:

While the family size does not affect the CWL for a single routine use, we strongly believe that these figures are very important for the purpose of this study and for future studies to estimate the CWL for families in Jordan.

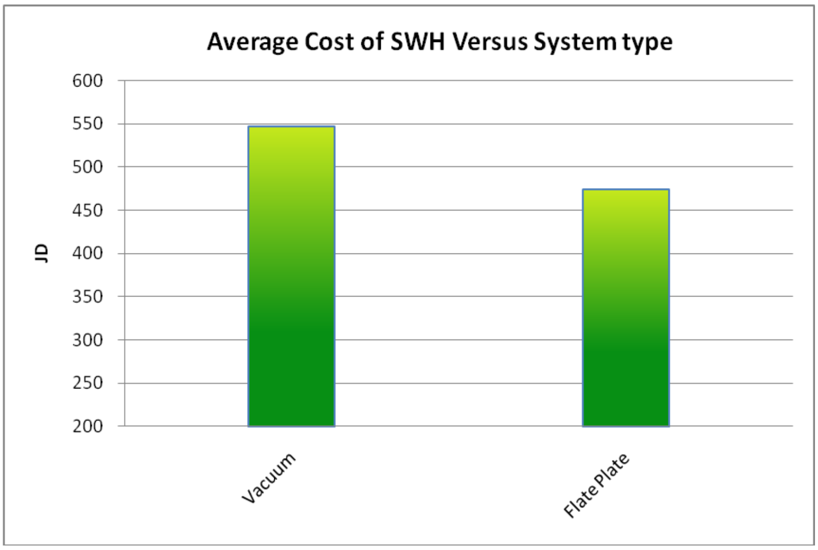
Jordan is a water poor country and the water resources are being depleted year after year. The average family size in Jordan is five members. Considering that 13% of the families in Jordan have solar water heaters, then approximately 130,000 families have solar water heaters.

The average number showers per week for a five-member family are 10.9 and the average weekly water losses per family is 263 liters per week. If 130,000 families have solar water heaters, then the weekly CWL in Jordan during summer is 34,190 cubic meters. Sumer here extends from May through Sep (about 20 weeks). By considering these figures, we can come up with total losses of 683,000 cubic meters during summer.

3.9 Average Cost of Solar Water Heaters According to their Type (Vacuum System or Flat Plate)

The survey evaluated the average cost of the solar water-heating system according to its type. The data shows that the average cost of the vacuum solar water-heating system is JD546, while the average cost of the flat plate system is JD474.

Figure 12: Average Cost of Solar Water Heaters Vs System Type



Feedback and Comments:

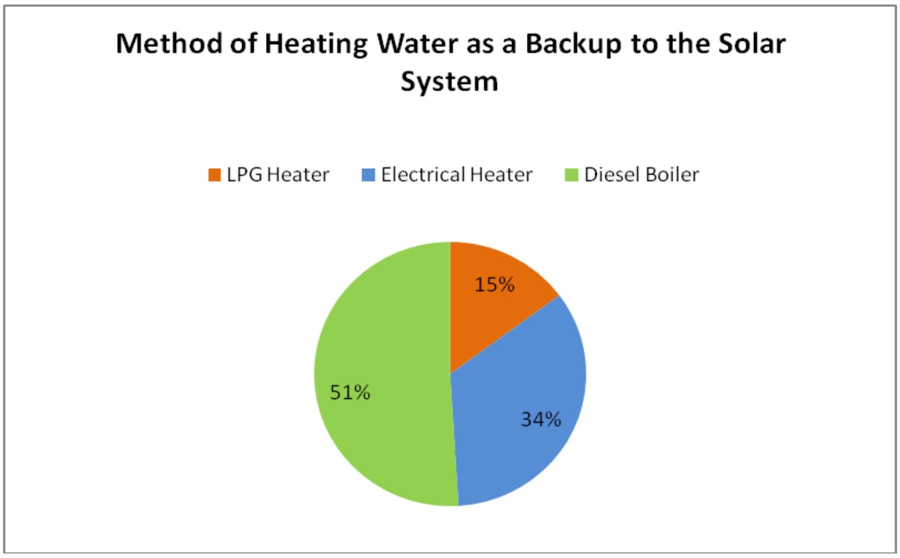
The cost of the vacuum systems was found higher than the flat plate system by about 15%. The efficiency of the solar water-heating system varies according to its quality, making the type of system less important than its quality.

3.10 Method of Water Heating as a Backup to the Solar Water-Heating System.

The households in the survey used three types of heating methods to back-up their solar water-heating systems during winter and intermediate seasons and for their heating source before installing the solar water system: diesel boiler, electrical heaters and LPG heater.

The survey showed that 51% of the sample uses diesel boilers for water heating, 34% uses electrical heaters and 15% use LPG boiler.

Figure 13: Method of Heating Water as a Backup to the Solar water-heating system



3.11 Customer Satisfaction:

The surveyors asked the households about their satisfaction with the solar water heaters to find out if there are any existing or previous problems with the systems.

Of the sample, 4% said they are not satisfied with the solar water-heating system due to the system's low efficiency, high CWL, water leaks or the capacity of the system.

On the other side, 17% said their system is good and it had no problems, but they feel that there are other systems in the market better than theirs.

The majority, 79%, said their system is excellent and they would recommend similar systems to their relatives and friends.

Figure 14: Customer Satisfaction Percentage

Feedback and Comments:

The dissatisfaction in 4% of the surveyed households was mainly due to the following reasons:

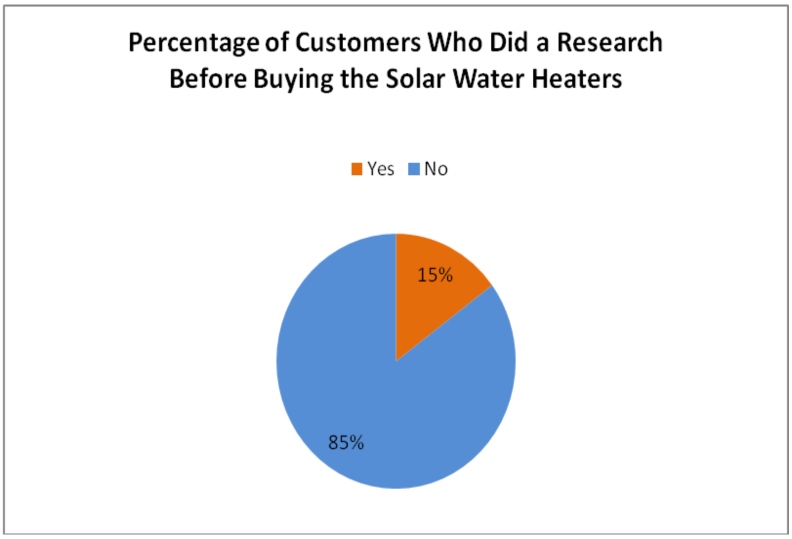
- Low system efficiency
- High cold-water losses
- High maintenance costs (leaks, fitting damages, sealants damages, etc.)

It's worth noting that the dissatisfied customers were often those who had installed cheap systems, which are often assembled in small workshops by non-professional technicians and limited engineering knowhow is evident in these systems.

3.12 Customer Who Did Research Before Buying the Solar Water Heaters:

The survey looked at the method used by the households to decide whether or not to buy the solar water heaters. The results showed that only 15% of the sample did any research and market visits to evaluate the prices and to select the suitable solar water-heating system for their needs. The majority (85% of the sample) said they installed their system based on a recommendation from their friends or relatives.

Figure 15: Customer Who Did Research Before Buying the Solar water-heating system.



Feedback and Comments:

The 15% of the sample who did research before buying the solar water-heating system were found to be more highly educated people. They had visited many suppliers and asked about the solar water-heating system specifications in order to select the best system for their needs. All of those customers were satisfied with their systems.

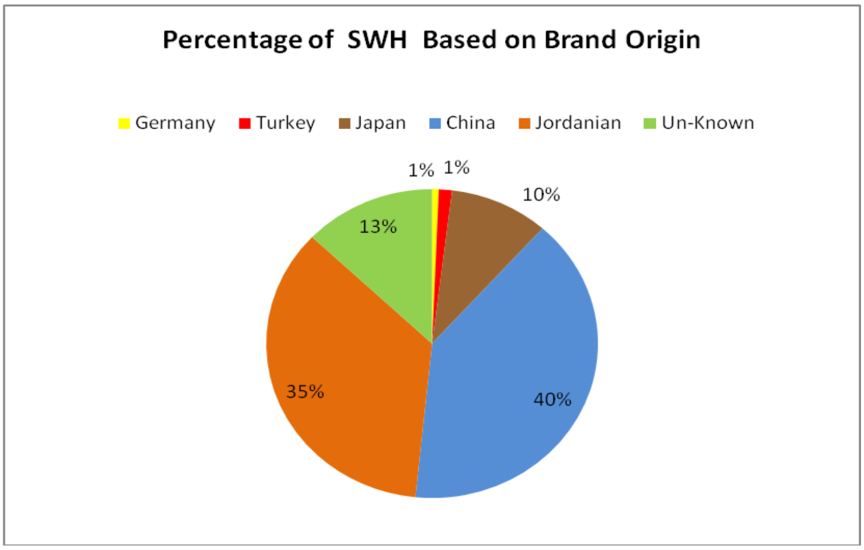
In marketing theory, word of mouth is a well trusted source and it has been widely used in the marketing of solar water heaters. Accordingly, we believe that this type of marketing is very useful to help reduce the percentage of dissatisfied customers and to help them avoid installing inefficient solar water heaters.

3.13 The Distribution of the Solar Water Heaters Based on the System Origin.

Many suppliers exist in the market providing a diversified range of solar water heaters from different countries. The survey found that the majority of the solar water heaters were manufactured in China representing about 40% of the visited sample. Jordan followed with 35%, then Japanese systems with 10% and Turkey and Germany each represented 1% of the sample.

Some systems were very old, and the brand or supplier name was not mentioned or erased by weather. Additionally, these households were unable to identify the supplier or the origin of their system. Those represented about 13% of the visited sample.

Figure 16: Percentage of Solar Water Heater Based on Brand origin.



Feedback and Comments:

The majority of the solar water heaters about (75% of the sample) were originated in China or Jordan. The Jordanian manufactured solar water-heating systems were mainly the flat plate type, while the Chinese origin solar water heaters were mainly vacuum systems.

The other brands (Japanese, Turkish and German) were less common due to the higher installation costs of these systems.

3.14 Theoretical Calculations of the CWL for 50 Households (32% of the Visited Sample):

The below table shows a comparison between the measured cold-water losses and theoretical calculations.

Table 7: Theoretical Calculations of the Cold-water losses

Number	Customer Sample	Total Number of Floors in the Building	Apartment Floor Level	Equivalent-Floor Level	CWL (Liters)	Distance Between Solar Water-Heating System and the Most Distant Showerhead (Meters)	Theoretical Calculations of the CWL (Liters)
1	Customer Sample 1	4	2	3	6	14	7.1
2	Customer Sample 2	4	4	1	3	10	5.1
3	Customer Sample 3	4	2	3	7	14	7.1
4	Customer Sample 4	4	2	3	8	22.8	11.5
5	Customer Sample 5	4	3	2	5	18	9.1
6	Customer Sample 6	4	4	1	3	8	4.1
7	Customer Sample 7	1	1	1	5.5	11	5.6
8	Customer Sample 8	4	3	2	8	22	11.1
9	Customer Sample 9	5	2	4	7	21.7	11.0
10	Customer Sample 10	5	4	2	4	12	6.1
11	Customer Sample 11	5	3	3	10	22	11.1
12	Customer Sample 12	4	4	1	8	18	9.1
13	Customer Sample 13	3	2	2	10	20.5	10.4
14	Customer Sample 14	2	2	1	3	7.5	3.8
15	Customer Sample 15	2	1	2	7	14	7.1
16	Customer Sample 16	2	1	2	3.5	10	5.1
17	Customer Sample 17	4	4	1	3	9.5	4.8
18	Customer Sample 18	4	3	2	10	21	10.6
19	Customer Sample 19	3	3	1	4	6	3.0
20	Customer Sample 20	1	1	1	9.5	14	7.1
21	Customer Sample 21	5	1	5	10	23	11.6
22	Customer Sample 22	2	2	1	12	19	9.6
23	Customer Sample 23	4	3	2	6	16	8.1
24	Customer Sample 24	4	1	4	8	25.3	12.8
25	Customer Sample 25	1	1	1	20	36	18.2
26	Customer Sample 26	4	2	3	13	22.5	11.4
27	Customer Sample 27	5	1	5	12	32	16.2
28	Customer Sample 28	4	4	1	4	11	5.6
29	Customer Sample 29	4	1	4	7	26	13.2
30	Customer Sample 30	5	1	5	10	28	14.2
31	Customer Sample 31	4	2	3	9	19	9.6
32	Customer Sample 32	4	4	1	4	12	6.1
33	Customer Sample 33	2	1	2	8	17.7	9.0

Number	Customer Sample	Total Number of Floors in the Building	Apartment Floor Level	Equivalent-Floor Level	CWL (Liters)	Distance Between Solar Water-Heating System and the Most Distant Showerhead (Meters)	Theoretical Calculations of the CWL (Liters)
34	Customer Sample 34	2	1	2	7.5	16	8.1
35	Customer Sample 35	3	1	3	10	18	9.1
36	Customer Sample 36	4	2	3	9	26.5	13.4
37	Customer Sample 37	4	3	2	4	13.5	6.8
38	Customer Sample 38	4	1	4	13	29	14.7
39	Customer Sample 39	4	3	2	7.5	14.9	7.5
40	Customer Sample 40	4	2	3	7.5	17	8.6
41	Customer Sample 41	4	2	3	6	14	7.1
42	Customer Sample 42	3	3	1	6	14.5	7.3
43	Customer Sample 43	5	1	5	13	29	14.7
44	Customer Sample 44	4	1	4	10	23	11.6
45	Customer Sample 45	2	2	1	8	14	7.1
46	Customer Sample 46	4	4	1	10	18.4	9.3
47	Customer Sample 47	5	3	3	8	21	10.6
48	Customer Sample 48	5	3	3	7	17	8.6
49	Customer Sample 49	4	1	4	14	32.1	16.3
50	Customer Sample 50	3	2	2	6.5	11	5.6

From the above table, it should be noted that the variation between the calculated CWL and the measured CWL is minimum and the average variance was 1.3 liters.

Note also that the pipe size of the above mentioned theoretical calculations considered a pipe of 1/2 an inch (12.7mm). The equation below was used in the above calculations:

$$CWL = \pi \cdot r^2 \cdot h$$

Where:

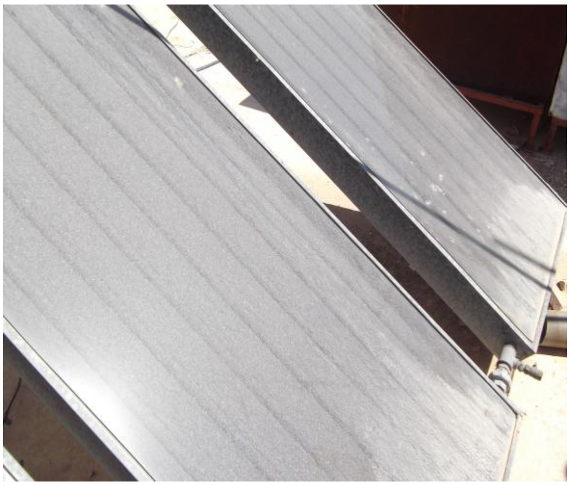
$\pi = 3.14$
r: is the radius of the pipe.
h: is the length of the pipe.

4.0 GENERAL OBSERVATIONS:

This chapter addresses observations recorded by our teams during the site visits. These include issues and problems that were found at a considerable number of the visited households. Many of the problems regard issues affecting the market penetration of solar water-heating systems in Jordan and reductions in the efficiency of the systems, which causes customers to be dissatisfied with the technology.

4.1 Cleanness of the Solar Collectors

During the site visits and the evaluation of the solar water-heating systems, the technical teams found that the majority of the solar water heaters were covered by a considerable layer of dust, preventing solar rays from reaching the collector and reducing the systems' efficiency. Here are a few representative examples:



Solar collectors should be kept as clean as possible. A periodically cleaning program (once per month at a minimum) will improve the system's efficiency by providing higher water temperatures, especially in the intermediate season. This will increase the span of time the households rely on the solar water heaters, which saves energy and reduces dependency on the backup heating system.

4.2 Factors That Cause the Low Percentage of Market Penetration of Solar Water Heaters in Jordan

According to previous research by PAP, it only 14% of Jordanian households have solar water heaters, despite the fact that solar radiation is very high and the solar water heaters are economically feasible, with a payback of three years on average. During the site visits and the evaluation, the technical team found that rooftops are occupied by water tanks, satellite dishes and scrap. This limited the available space for solar water heaters to three or four collectors, while most of the buildings host between nine and 12 families.

Water tanks occupy the majority of space on the roof.

Satellite Dishes were installed randomly, occupying considerable space.

Moreover, the space required by some systems (the flat plate systems require more space than the vacuum system) also reduced the free space on the roof and consequently prevented other occupants from installing systems. While some systems are compact and need an area of about 4 to 6 square meters, others need up to 10 to 12 squares meters.

This further limited the available area on rooftops, and was found many times during the survey. The photos below illustrate the two types of systems and the area required for each.

Space required by Vacuum Solar Water Heaters

Space required by Flat Plate Solar Water Heaters

4.3 Family Income and the Orientation to the Use of the Solar Water Heaters.

During the site visits, the technical teams found that most of the households that had installed a solar water-heating system have a medium income. This was determined by the type of furnishings they have in their homes. Medium-income families can afford to buy solar water heaters to save energy costs for heating.

On the other hand, the high-income households were of a limited number in this sample. At this stage, this point should not be considered conclusive, though other research has shown that well-paid people or high-income people care less about fuel or electricity bills, which comply with our observations.

5.0 RECOMMENDATIONS:

This chapter addresses the recommended practices to reduce CWL in the residential sector, which will save the displaced cold water as well as save energy. The below recommendations were derived from the analysis of the data collected from the survey and the measurements at the households.

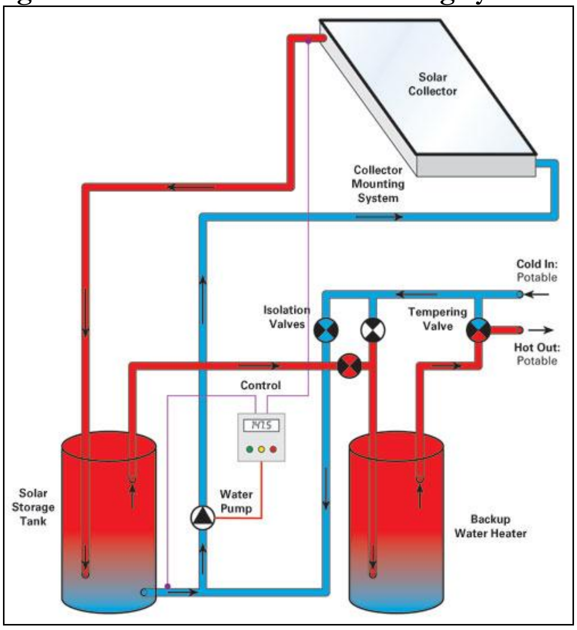
1. **Install a Circulation Pump for the Hot Water**

   Thousands of cubic meters are being wasted to the drain in Jordan each year when homeowners wait for their water to reach a comfortable temperature before they shower. In conventional hot water systems, water runs from the Solar water heater to each water fixture (including the showerhead), leaving some water in the pipes to cool. When a homeowner turns on a shower head, the cooled water sitting in the pipes circulates to the shower first, so the homeowner has to wait for hot water.

   A simple and inexpensive way to minimize the CWL occurred until hot water reaches the shower is to install circulation a "hot Water Circulation Pump" in new installed systems. Hot water circulation pump sends cool water in the pipes back to the solar water heater through a return line. A pump circulates this water through the solar water heater as needed to keep it hot. This continuous loop of water through the water heater ensures that hot water is always available. It's worth to be mentioned here that the circulation pump is not similar to the "booster pump" which is used to pressurize the water in the water network for user satisfaction.

   As the CWL is being increased when the distance between the solar water heater and the end user increased, it is highly recommended to install the circulation pump system for the customers who lives in the lower floor levels in the apartment (Ground Floor and first Floor). As for the upper level floors, it is recommended also to install a circulation pump system if the hot water pipes are following a distant path; this will reduce the CWL losses dramatically. The below figure illustrates the concept of the circulation pump.

Figure 17: Schematic Diagram of Forced Solar water-heating system with "Circulation Pump"



2. **Proper Selection of the Solar water-heating system's Location, Pipe Size and the Hot Water Pipes Path.**

   The solar water-heating system's location should be studied well before the installation, to select a location as near as possible to the riser of the building or to the entering point to the apartment, the plumbers and technicians who install the solar water system shall be aware of the best practices for installing the solar water heaters including the solar water-heating system location.

   Households also should be aware by the impact of the wrong location of the solar water heaters on the amount of the CWL. Many of the technicians and plumbers were found non skilled enough to install the solar water heaters according to the best practices. Those technicians and plumbers shall attend specialized training courses (accredited courses) to improve their knowledge about the best practices including the minimization of the CWL.

   On the other hand, the households awareness have to be improved by this problem so they can interact with the technicians helping them to select the best location on the roof, awareness level for households could be improved by the media , caricatures or leaflets.

   Other part of the problem is the wrong path and the wrong pipe size, the hot water pipes should be correctly sized to avoid big size (1/2 inch was found enough and satisfactory) , additionally the wrong routes of hot water pipes increase the distance and consequently the CWL. The hot water path shall be on the shortest route to the targeted apartment with no exaggerated loops.

3. **Install a High Efficiency Insulation Layer.**

   Pipes insulation is a very important factor in reducing the CWL in any hot water system including the solar water heaters. Insulation layer reduces the thermal energy losses from pipes and keeps the hot water temperature for longer period so as when any usage of the shower or water fixture, the household has not to wait for long period till the hot water reaches and saves water and energy at the same time.

   During the field assessment, it was noticed that a limited number of the hot water pipes were insulated (15% of the total sample). None insulated pipes increase the CWL dramatically, therefore, it is highly recommended to provide an insulation layer over the hot water pipes to help in reducing the CWL.

   Insulation layer found on the 15% of the sample was made from sponge; sponge insulation is not an effective insulation if compared to the rock wool insulation.

   However, the high cost (approx JD 10 per meter) for the rock wool insulation posts an additional considerable cost to the solar water-heating system cost making it unaffordable by many households.

   When it comes to the low floor apartments, the amount of the lost water and the heat energy lost for the backup water in some cases makes it feasible if it was affordable by the household.

   Accordingly, it is recommended to install a rock wool insulation layer over the hot water pipes for the low floor apartments to save water and energy.

4. Building capacity for vocational training programs for technicians in the SWH and plumbing industry

5. Building capacity for engineering training programs for engineers who design and supervise implementation of plumbing works

6. Enforcement of codes:
    a. Create penalty schemes for improper installations
    b. Establish auditing committees that make random checking on constructions
    c. Give these committees incentives in order to motivate them

6.0 CONCLUSION

As a result of the field assessment of domestic solar water heaters in Amman - Capital of Jordan. it was found that the cold-water losses varies from 2 liters up to 24 liters measured at different dwelling units from the ground floor and up to the fifth floors, this high variance is related to many reasons as the following :

1. The distance between the solar water-heating system and the end use, by the increment of this distance the CWL is increased.
2. Most of the solar water heaters users had installed a thermosiphon pumping system which also increases the cold-water losses; some of the visited households have a circulation pump for hot water which reduces the cold-water losses.
3. No or week insulation layer were found on the hot water pipes which results in losing the thermal energy for the hot water stored in the pipes in less time.
4. Pipe sizes were found mostly of 1/2 inch (12.7 mm) while few households were found of higher sizes 3/4 inch (19 mm).

The above mentioned points are considered as the major factors in increasing the cold-water losses at the household level.

The above mentioned factors could be treated and solved to help in reducing the cold-water losses in the solar water-heating system, these factors could be solved by the below mentioned procedures:

1. Installation of a circulation pump for systems installed far away from the end user.
2. Reducing the hot water pipe length as much as possible through successful selection of the solar water heater location and the hot water routes.
3. Correctly size the pipe diameter and avoid installing big pipe sizes, 1/2 inch (12.7 mm) was found enough and satisfactory.
4. Providing an insulation layer over the hot water pipes to reduce the thermal losses and increase the system efficiency.

Most of the above mentioned factors are technical, the technicians and plumbers who install the solar water heaters shall be aware by these problems to avoid installing the solar water-heating system in a non effective way. Training courses and accreditation for plumbers and technicians is needed to have more skilled and more experienced technicians.

On the other hand, the field assessment and site visits showed some other factors needs to be investigated further which limits the penetration of the solar water heaters at the household level, these factors are summarized as below:

- Limited available free space on the building roofs which was found occupied by huge number of water tanks and satellite dishes.
- Low or no periodically maintenance of the solar collectors which reduces its efficiency and leads the customer to be dissatisfied from the solar water heater, and as shown in the study findings, the word of mouth is the most attempted tool for marketing of the solar water systems.
- Medium income households are the majority who installed a solar water heaters, while high income households don't believe by the concept of energy or water saving.

  It is strongly believed that the recommendations presented in this report will solve many of the problems related to the cold-water losses, at the same time; further investigations and viable solutions for the factors which limits the solar water heaters penetration in the Jordanian market will assist in more dependency on the solar water heaters to save energy cost.

7.0 ANNEXES

7.1 Annex A: List of Abbreviations:

SWH : Solar Water Heater

CWL : Cold-water losses

LPG: Liquefied Petroleum Gas

7.2 Annex B: Definitions:

Equivalent-floor level: The equivalent-floor level is defined as total number of floors falls between the solar water-heating system and the apartment.

Forced Pumping Solar water-heating system: The forced pumping solar water-heating system is a type of pumping used to circulate the hot water between the solar water-heating system and the end user or the hot water cylinder.

Circulation pump: The circulation pump is a pump used to sends cool water in the pipes back to the solar water heater through a return line.

Booster Pump: The booster pump is a pump used to increase the water pressure in the water network for human satisfaction and it does not do any water circulation.

Thermosiphon Solar water-heating system: the thermosiphon refers to a method of passive heat exchange based on natural convection which circulates liquid without the necessity of a mechanical pump..

Vacuum Solar Collector: Is a type of solar collector in which heat loss to the environment, has been reduced. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes.

Flat Plate Solar Collector: Is a type of solar collector which consist of a dark flat-plate absorber of solar energy, a transparent cover that allows solar energy to pass through but reduces heat losses, a heat-transport fluid flowing through tubes to remove heat from the absorber.

East of Amman : for the purpose of this study, the following districts in Amman have been classified under east of Amman: tabarbour, Sport city, Dahyet Al -Aqsa, Al-Hashemy Al-Shamaly, Al- Ourdon Street , Jabal Al-Ashrafeyeh, Daheyet Al-Amir Hasan.

West of Amman : for the purpose of this study, the following districts in Amman have been classified under west of Amman: Swelieh, Tla Al-Ali, Al-Jandaweel, Daheyet Al-Rawdah, Marj Al-Hamam, Abdoun, Swifeyeh, Khilda, Daheyet Al-Rasheed, Shifa Badran, Al-Jubaiha, Mecca Street, Daheyet Al-Rasheed, Al-Sarew, Daheyet Al-Sadeq, Daheyet Al-Farouq, Abu Nsier, Deir Ghbar, Shmesani, Gardens Street, Wadi Saqra, Al-Rabyeh, Um -Alsommaq

7.3 Annex C: Field Visit Questionnaire:

Public Action for Water, Energy and Environment

Field Data Questionnaire

Date:	• Time:
Field Staff:	• Client Name:
Location:	• Type of Dwelling:
Client Phone No.:	• Family Size:
Weather:	• Total Number of Floors for the Building:
Apartment's Floor Level:	• System Technology (Flat Plate or Vacuum):
Solar water-heating system Age:	• Vendor Name:
System Condition (functioning well, broken never repaired; dust covered, not maintained):	• Distance (Between SWH and Furthest showerhead)-Meters:
if the cold water reject is high, what is the best solution to reducer it	the pipe size of the solar water-heating system
System Type (Thermosiphon or Forced):	• Country of manufacture:
Circulation Pump (yes / no):	• Pipe Insulation (yes / no):
Type of insulation:	• Volume of cold water (Litres):
Method of measurement:	• How many showers per week (for the whole family):

System cost (including installation):	• Method of water heating before installing SWH (What is the fuel type for that):
Was customer given recommendations before the system was installed?	• Customer Satisfaction for the system:

Notes and Comments