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Experimental investigation of the thermosiphonic phenomenon in domestic solar water heaters

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Abstract-- The deeper understanding of the 'thermosiphonic phenomenon' and the identification of the key parameters affecting it, is the main aim of a research project currently in process in Cyprus. In this work a review of the existing standards and scientific knowledge concerning domestic solar water heaters is presented. The first preliminary results of the experimental investigation of the 'thermosiphonic phenomenon' in domestic solar water heaters are also presented. For this purpose a special test rig was set up and equipped with all sensors necessary to measure all parameters that are most likely to affect the 'thermosiphonic phenomenon'. All tests were conducted according to ISO 9459-2:1995(E). At first, the solar collector was tested according to EN12975-2:2006 in order to determine the thermal performance characteristics at a flow and operation conditions specified by the standard. Consequently, the efficiency of the collector operating thermosiphonically was calculated based on quasi-dynamic approach. Finally, a series of correlations were attempted using the data acquired when the collector is operating themosiphonically which are the following: (i) the temperature difference of the water at the outlet and the inlet of the collector (ΔT) with the solar global radiation, (ii) the water mass flow with the solar global radiation, (iii) the water mass flow with the temperature difference of the water at the outlet and the inlet of the collector (ΔT). The results of the data analysis showed that these parameters are very well correlated between them since the coefficient of determination (R^2) is over 0.91 in all cases.

Index Terms-- **Cyprus, Solar water heaters, Thermosiphonic phenomenon.**

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I. INTRODUCTION

CYPRUS has no natural oil resources at the moment and relies entirely on imported fuel for its energy demands.

The only natural energy resource available is solar energy. Cyprus has a very sunny climate with an average annual solar radiation on a horizontal surface of 5.4 kWh/m^2-day.

Solar water heating units are extensively employed in Cyprus. In fact the total number of units installed, are such that constitute Cyprus to be the leading country in the world in this area. These units are mostly of the thermosiphonic type. This type of solar water heater consists of two flat-plate solar collectors having an absorber area between 3 to 4 m^2, a storage tank with capacity of 150 to 180 litters and a cold water storage tank, all installed on a suitable frame. An auxiliary electric immersion heater and/or a heat exchanger, for central heating assisted hot water production, are used in winter during periods of low solar insolation.

Because the manufacturing of solar water heaters and mainly that of the thermosiphon type has expanded rapidly in Cyprus, there is a need to study in depth and model this type of systems. It is also required to validate the model using simple physical experiments. In this way the model can be used to investigate the effect of design changes and therefore improve the solar water heater performance.

II. LITERATURE REVIEW

There have been extensive analyses of the modelling, analysis and performance of thermosiphon solar water heaters, both experimentally and analytically by numerous researchers [1]. Some of the most important are shown here.

Close [2] made the first published analysis of thermosiphon solar water heater circuit. He has presented a mathematical model where mean system temperature and water mass flow rate can be predicted by testing two thermosiphon systems with different characteristics. The results conformed well to those predicted.

Desa [3] considered the water heater system on the whole and by equating the incident energy received to the sum of the heat losses from it and the heat gained by the water, predicted the mean water temperature variation throughout the day for a natural circulation flow system.

Gupta and Garg [4] modified the model of Close [2] to take into account the heat exchange efficiency of the collector absorber plate and thermal capacitance. They have improved on Close's analysis by incorporating a plate efficiency factor to account for the thermal efficiency of the plate and approximating ambient conditions using Fourier's series expansions for ambient temperature and radiation intensity. So they developed a model for thermal performance of a natural circulation solar water heater with no load and presented solar radiation and temperature with Fourier series. They also found experimentally that the flow rate of a thermosiphon water heater can be increased by increasing the relative height between the collector and storage tank, but the efficiency is not increased. The efficiency can be increased by reducing the loop resistance.

Ong [5,6] evaluated the thermal performance of a thermosiphon solar water heater. He used a small system with five thermocouples on the bottom surface of the water tubes and six thermocouples on the bottom surface of the collector plate. The six thermocouples were inserted into the storage tank and a dye tracer mass flow meter was employed. His studies were the first detailed ones on a thermosiphonic system. Ong [5] extended the work of Close [2] and Gupta and Garg [4] as he presented a finite difference method of solution to predict the mean system temperature and water mass flow rate in a solar water heater operating under thermosiphon flow conditions. The experimental results presented, showed that the mean collector plate temperature, the average water temperature in the storage tank and the mean water temperature in the collector tubes were not equal. Furthermore, the tank temperature distribution was non-linear. All these were contrary to the theoretical assumptions that the mean temperatures were equal, corresponding to a single mean system temperature and that the tank temperature distribution was linear. In [6] he wanted to improve the theoretical assumptions made previously in [5], in order to obtain a more satisfactory agreement between experimental data and prediction. Therefore, in [6], an improved theoretical model was presented to predict the thermal performance of a natural-recirculation solar water heater system.

Shitzer *et al.* [7] made experiments with a flat plate solar water heating system in thermosiphonic flow and observed linear temperature distributions both along the collectors and in the storage tank when no hot water consumption was allowed. They also found that water flow rate essentially follow solar radiation and reached a maximum of 0.95 l/min which is about 33% smaller than the value they predicted by an analytical model. However, they observed that by shutting the system off during the afternoon hours, when losses to the environment increases, might increase the efficiency of the system.

Morrison and Ranatunga [8] investigated the response of thermosiphon systems to step changes in solar radiation. Measurement of the transient flow rate was obtained using a laser Doppler anemometer and a mathematical model was developed to simulate the transient performance. Results shown that although there are long time delays associated with the development of the thermosiphon flow the energy collection capability is not affected by thermosiphon time delays.

Hahne [9] calculated the efficiency and warming up time of flat plate water collector under steady state and transient state conditions. Comparison of collector performance in summer and winter shows the importance of collector inclination and the effect of pipe spacing.

Morrison and Sapsford [10] investigated the performance of 6 thermosiphon solar water heaters while they were supplying typical domestic hot water loads. The performance of the solar systems was rated by comparing the auxiliary energy consumption with the energy consumed by a conventional electric system. In contrast to forced circulation systems the performance of thermosiphon systems was found to be best if a morning peak load pattern was used. Their results showed that the performance of thermosiphon solar water heaters is a function of the way the system is operated and that significant variations of performance exist between different systems configurations.

The results from the two previous studies have been used by Morrison and Tran [11] to develop a simulation program for thermosiphon solar water heaters supplying various domestic energy demand patterns. Morrison and Tran [11] presented a finite element simulation model for prediction the long term performance of thermosiphon solar water heaters. The simulation results indicate that the performance of a solar water heater with an in-tank booster improves as the flow rate through the collector is reduced. Also found that the efficiency of a thermosiphon system with in-tank booster is slightly higher than an equivalent pumped circulation system, due to better stratification in the storage tank in the thermosiphon system.

Kudish *et al.* [12] used a standard Israeli solar collector consisting of eight cooper tube risers connected to two cooper tube headers. They studied the effect of the height of the thermosiphon head on the flow rate. The rate of thermosiphon flow was measured periodically throughout the day during the sunshine hours so they determined the instantaneous collector efficiency through a day. They measured the thermosiphon flow rate directly by adapting a simple and a well known laboratory technique, using a constant level device to a solar collector in the thermosiphon mode. The data for the thermosiphon flow were used to construct a standard efficiency test curve so as to prove that this technique can be applied for collector testing as a standard laboratory technique. The correlation between the thermosiphon flow and the global insolation was observed to be linear in all cases studied.

Morrison and Braun [13] studied system modelling and operation characteristics of thermosiphon solar water heater with vertical and horizontal storage tank. They found that system performance is maximized when the daily collector volume flow is approximately equal to the daily load flow. Very important is the fact that they found that the system with vertical tank can perform better than the horizontal one. They found good agreement between the simulation results and experimental data as they compared an efficient numerical simulation model for thermosiphon solar water heaters for two locations. The model they used has also been adopted by TRNSYS simulation program.

Hobson and Norton [14] made the characteristic curve for an individual directly–heated thermosiphon solar energy water heater obtained from data of a test period of 30 days. Using this curve they calculated the annual solar fraction which agreed well with the corresponding value computed from the numerical simulation. They produced a simple but relatively accurate design method for direct thermosiphon solar water heater.

Tiwari and Lawrence [15] studied a transient analysis of a closed loop solar water heater with heat exchanger under a thermosiphon mode with analytical expressions for fluid temperature in the flat plate collector and storage tank temperature.

Shariah and Shalabi [16] studied optimization of design parameters for a thermosiphon solar water heater for two regions in Jordan through the use of TRNSYS. Their results indicate that the solar fraction of the system can be improved by 10-25% when each studied parameter is chosen properly. Using the optimum or recommended values of the design parameters for a thermosiphon system could reduce the price of the system as well as improving the performance. However, solar fraction of a system installed in hot climate is less sensitive to some parameters than in mild climate. Shariah *et al*. [17] presented a comprehensive assessment of the impact of most of the design parameters on the performance of the thermosiphon water heating system and provide guidance on the `optimum' value for each. They used TRNSYS program to simulate the annual performance of thermosiphon water heating systems with meteorological data for Los Angeles.

Kalogirou and Papamarkou [18] studied the modelling of a thermosiphon solar water heating system with a simple model validation in Nicosia, Cyprus. They used two flat plate collectors with an area 2.7 m^2 and a storage tank of 150 l modelled using TRNSYS so to have a detailed analysis and a long term system performance. They found that the annual solar contribution of the simulated system was 79% and during the summer months no auxiliary heating is required as the solar contribution of the simulated system was 100%. This means that the solar fraction reached 100%. However, during the summer months the demand for hot water from storage tank was reduced. Experimentally they found that there is a decrease in solar radiation during May because of special conditions to the development of clouds encountered in Nicosia. They also made an economic analysis which they found that the pay-back time of the system is 8 years and the present worth of life cycle savings is equal to 161 Cy pounds (€275).

Chuawittayawuth and Kumar ([19] presented details of experimental observation of temperature and flow distribution in natural circulation solar water heating systems. They found that the temperature values at the riser tubes the collector inlet are generally much higher than those at the other risers on a clear day, while on cloudy days the temperature is uniform. They concluded that the temperature of water in the riser depends on its flow rate. They also carried out the measurements of the glass temperature.

Jiang *et al*. [20] found that the thermal performance of a solar thermosiphon system for water heating depends on its design characteristics and manufacturing quality so they analyzed four characteristic parameters which helped them to assess not only the solar thermosiphon system performance but also the direction for system performance improvement.

Runsheng *et al*. [21] constructed and tested two sets of water in glass evacuated tube solar water heaters. Both systems were identical in all aspects but had different collector tilt angle from the horizon with the one inclined at 22° and the other at 46°. Experimental results showed that the collector tilt angle of solar water heater had no significant influence on the heat removal from solar tubes to the water storage tank; both systems had almost the same daily solar thermal conversion efficiency but different daily solar and heat gains and climatic conditions had a negligible effect on the daily thermal efficiency of systems due to less heat losses of the collector to the ambient air. This fact shows that to maximize the annual heat gain of such solar water heaters, the collector should be inclined at a tilt angle for maximizing its annual collection of solar radiation. A year before [22] they studied a thermosiphon domestic solar water heater with flat plate collectors at clear night and found that thermosiphon domestic solar water heater flat plate collectors with a non solar selective absorber might suffer from freezing damage.

Riahi and Taherian [23] presented a detailed review of other studies and made a detailed analysis by discussing and comparing their results with other studies. They have used the hydrogen bubble method to measure the flow rate as shown by Bannerot [24]. They collected data for several sunny and cloudy days. Also they studied dynamic response of the system to variations in solar insolation. It was found that such systems can provide ample energy to satisfy the demand for hot water.

Okonkwo and Nwokoye [25] made an experimental investigation of the performance of a thermosiphon solar water heater for a period of six months measuring the solar radiation, water mass, relative humidity and wind speed using special equipment.

Sakhrieh and Al-Ghandoor [26] made an experimental investigation of overall performance, efficiency and reliability of five types of solar collectors as used in the local Jordanian market. The five types that they studied are blue coated, black coated, cooper, aluminum and with evacuated tube. They observed that the outlet temperature (T_{out}) of the five types increases during the day and reaches the peak at about 2.00 p.m. and then starts to decrease. The efficiency curve against time has the same shape as the T_{out} curve. They concluded that evacuated tube solar collector has the highest efficiency followed by black and blue coated solar collectors. The aluminum collector comes in the fourth place as the lowest efficiency is reserved for the copper collector.

III. EUROPEAN STANDARDS

In April 2001 CEN started publishing a series of standards related to solar collectors and systems testing. With the publication of these European standards all national standards, related to the same topic and having conflicting provisions were (or have to be) withdrawn by the nations of the European Community. Some of these standards were revised in 2006 and are now under their second 5-year systematic review. A complete list of these standards is as follows:

EN 12975-1: 2006 +A1: 2010. *Thermal solar systems and components - Solar collectors - Part 1: General requirements*. This European standard specifies requirements on durability (including mechanical strength), reliability and safety for liquid heating solar collectors. It also includes provisions for evaluation of conformity to these requirements. (A1: 2010 in the standard reference number denotes a minor amendment which was made in 2010 to change the scope of the standard so as to extend its application for concentrating collectors as well).

EN 12975-2: 2006. *Thermal solar systems and components - Solar collectors - Part 2: Test methods.* This

European standard establishes test methods for validating the durability, reliability and safety requirements for liquid heating collectors as specified in EN 12975-1. This standard also includes three test methods for the thermal performance characterization for liquid heating collectors.

EN 12976-1: 2006. *Thermal solar systems and components - Factory made systems - Part 1: General requirements.* This European standard specifies requirements on durability, reliability and safety for factory made solar systems. This standard also includes provisions for evaluation of conformity to these requirements.

EN 12976-2: 2006. *Thermal solar systems and components - Factory made systems - Part 2: Test methods.* This European standard specifies test methods for validating the requirements for factory made solar systems as specified in EN 12976-1. The standard also includes two test methods for the thermal performance characterization by means of whole system testing.

EN 12977-1: 2012. *Thermal solar systems and components - Custom built systems - Part 1: General requirements for solar water heaters and combisystems.* This European standard specifies requirements on durability reliability and safety of small and large custom built solar heating and cooling systems with liquid heat transfer medium in the collector loop for residential buildings and similar applications. The standard also contains requirements on the design process of large custom-built systems.

EN 12977-2: 2012. *Thermal solar systems and components - Custom built systems - Part 2: Test methods for solar water heaters and combisystems.* This European standard applies to small and large custom built solar heating systems with liquid heat transfer medium for residential buildings and similar applications, and specifies test methods for verification of the requirements specified in EN 12977-1. The standard includes also a method for thermal performance characterization and system performance prediction of small custom built systems by means of component testing and system simulation.

EN 12977-3: 2012. *Thermal solar systems and components - Custom built systems - Part 3: Performance test methods for solar water heater stores.* This European standard specifies test methods for the performance characterization of stores that are intended for use in small custom built systems as specified in EN 12977-1.

EN 12977-4:2012. *Thermal solar systems and components - Custom built systems - Part 4: Performance test methods for solar combistores*. This European standard specifies test methods for the performance characterization of stores which are intended for use in small custom built systems as specified in EN 12977 1. Stores tested according to this document are commonly used in solar combisystems.

EN 12977-5:2012. *Thermal solar systems and components - Custom built systems - Part 5: Performance test methods for control equipment*. This European standard specifies performance test methods for control equipment as well as requirements on accuracy, durability and reliability of the control equipment.

EN ISO 9488: 1999. *Solar energy - Vocabulary (ISO 9488: 1999).* This European - International standard defines basic terms relating to solar energy and has been elaborated in common with ISO.

The elaboration of the above standards has been achieved through a wide European collaboration of all interested parties such as manufacturers, researchers, testing institutes and standardization bodies. Furthermore, these standards will promote a fair competition among producers of solar energy equipment on the market, since low-quality/low-price products will be easier to identify for the customers based on uniform test reports comparable throughout Europe.

The increased public awareness on environmental aspects will be reinforced from these standards, which will ensure the quality level for the consumer and will give him more confidence in the new solar heating technology and the products available.

IV. Solar Water Heaters Performance Evaluation

Many test procedures have been proposed by various organizations in order to determine the thermal performance of solar water heaters which include, integrated collector storage, thermosiphon and forced circulation systems, both custom and factory built. Testing of the complete system may serve a number of purposes. The main one is the prediction of the system long-term thermal performance. System testing may also be used as a diagnostic tool to identify failure and causes of failure of the system performance. Other purposes include the determination of the change in performance as a result of operation under different weather conditions or with a different load profile.

International Organization for Standardization (ISO) published a series of standards ranging from simple measurement and data correlation methods to complex parameter identification ones. International Standard ISO 9459 has been developed by the Technical Committee ISO/TC 180 – Solar Energy, to help facilitate the international comparison of solar domestic water heating systems. Because a generalized performance model, which is applicable to all systems, has not yet been developed, it has not been possible to obtain an international consensus for one test method and one standard set of test conditions. Therefore, each method can be applied on its own.

A total of five parts comprise ISO 9459 on solar domestic water heater performance testing as described below with their current status:

ISO 9459-1: 1993-*Solar heating - Domestic water heating systems. Part 1: Performance rating procedure using indoor test methods.* →ACTIVE

ISO 9459-2: 1995-*Solar heating - Domestic water heating Systems. Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems.* →ACTIVE (referenced in EN 12976)

ISO 9459-3: 1997- *Solar heating - Domestic water heating systems. Part 3: Performance test for solar plus supplementary systems.* →WITHDRAWN in 2005

ISO/DIS 9459-4-*Solar heating - Domestic water heating systems. Part 4: System performance characterization by means of component tests and computer simulation.* →UNDER DEVELOPMENT, ISO/FDIS 9459-4 published October 2012 (FDIS=Final Draft International Standard)

ISO 9459-5: 2007-*Solar heating - Domestic water heating systems. Part 5: System performance characterization by means of whole-system tests and computer simulation.* →ACTIVE (referenced in EN 12976)

V. STANDARDISATION WORK IN PROGRESS

A. Modifications in existing standards

Currently the two standardization technical committees are discussing modifications in the various published standards. At European level, CEN/TC 312 is now working on the amendment of EN 12975-1, EN 12976-1 and EN 12976-2. At European and International levels, both CEN/TC 312 and ISO/TC 180 are co-operating to review EN 9488 and ISO 9806 (Solar Energy-Solar thermal collectors-Test methods). The latter, will include all the provisions and requirements of EN 12975-2 and will be published as a European-International EN ISO standard replacing all three existing parts of ISO 9806 as well as EN 12975-2.

B. New standards proposed or under development

A new draft standard has been developed by CEN/TC 312 concerning the determination of the long term behaviour and service life of selective absorbers for use in solar collectors working under typical domestic hot water system conditions. This will form one of the parts of the new standard EN ISO 22975 - *Solar Energy-Collector Components and materials*. Under the approval of the two committees is also a proposal for the development of two more parts to be included in the standard:

- *Evacuated tubes – Durability and performance*
- *Heat pipes for evacuated tubes – Durability and performance*

Furthermore, ISO/TC 180 is also developing ISO/DIS 9459-4 (now available as ISO/FDIS) which has already been described in previous sections.

VI. STANDARDS RELATED TO THERMOSIPHONIC SYSTEMS

It is clear from the above review that there is no standard related to the testing of flat-plate collectors, for the purpose to determine its characteristics and most important weather the collector is able to generate the thermosiphon effect, so as to indicate that such a collector is suitable for use in a thermosiphon system. Concerning the system testing, as the performance of the system is determined by measurements made irrespective of the type of system, the existing standards are considered adequate to be used to the thermosiphon systems as well.

VII. DESCRIPTION OF THE TEST RIG

The thermosiphon test rig used for the experimental procedure, shown in Fig. 1, was assembled by the staff of Applied Energy Laboratory of the Cyprus Ministry of Commerce, Industry and Tourism and consists of three main components namely the Test Rig, the Cylinder and the Heat Sink which are described below.

The Test Rig is made out of galvanized steel and it was designed to adjust the angle of collector. For the adjustment of the angle of the collector, a fully automatic pneumatic stroke is installed. The angle of the collector is measured with an inclinometer. In addition, the Test Rig is designed so that the height between the collector and the Cylinder can be adjusted. Additionally, a pyranometer is attached on the Test Rig, in order to measure the global radiation during the test period.

The Cylinder is made out of copper and it is insulated with natural mineral wool. Sensors are attached on the cylinder, for recording the temperature of the water such as:

1. Inlet Temperature (2 x PT100)
2. Outlet Temperature (2 x PT100)
3. Draw off inlet and outlet (2 x PT100)
4. Mixing temperature (2 x PT100)
5. Stratification temperature (5 x Thermocouple)
6. Inlet and Outlet of the Heat Exchanger (2 x PT100)

Fig. 1 Front view of the test rig

A pneumatic ball valve is attached at the draw off outlet in order to regulate the flow at the draw off period. In addition, a mixing pump is attached at the back of the cylinder. Furthermore, the cylinder is equipped with a magnetic flow meter for measuring the flow at the exit of the collector, and a second portable ultrasonic flow meter is attached at the inlet pipe of the collector. It has also a differential pressure transmitter for measuring the pressure drop of the collector.

A supply tank is used as Heat Sink, which provides water to the system. At the exit of the supply tank, there is a three-way valve with an actuator, and a pump. This allows regulating the temperature and flow of the water which is provided to the system.

VIII. METHODOLOGY

The data analysed in this paper were recorded using Agilent data acquisition equipment between the 29th of May and the 13th of June. The data were recorded from 07:30 to 18:45. The area of the collector used for the experiments was 1.36m^2, its orientation was south and its inclination angle was constant at 45°, which is the angle used by most solar water heating systems in Cyprus.

Initially, the solar collector was tested according to EN12975-2: 2006 in order to determine the thermal performance at a flow and operation conditions specified by the standard. According to the standard, the experimental parameters needed to compute the collector's efficiency under constant inlet temperature and mass flow during a test period, are the water temperature at the collector inlet, water temperature at the collector outlet, water mass flow, solar global radiation, ambient temperature and wind speed. Subsequently, the test was repeated with the collector operating thermosiphonically.

Several correlations were attempted as follows:

(i) temperature difference of the water at the outlet and the inlet of the collector (ΔT) with the solar global radiation,

(ii) water mass flow with the solar global radiation,

(iii) water mass flow with the temperature difference of the water at the outlet and the inlet of the collector (ΔT).

All tests were conducted according to ISO 9459-2:1995(E).

IX. Results and Discussion

The results concerning the thermal performance of the collector according to EN12975 and under thermosiphonic operation are depicted in Fig. 2. It can be observed that the thermal performance according to EN12975 is slightly higher than that of the thermosiphonic operation, which is rather logical due to the fact that the flow during the thermosiphonic operation is lower than the one according to EN12975 since it is naturally created as a result of the temperature difference between the inlet and the outlet water of the collector (thermosiphonic phenomenon). The equation of the performance of the collector according to EN12975 is:

$$h = 0.7025 - 4.3377\frac{T_m - T_a}{G} - 0.1630\frac{(T_m - T_a)^2}{G} \qquad (1)$$

The results correlating the solar global radiation (G) with the temperature difference between the water inlet and outlet of the collector (ΔT) are depicted in Fig. 3 where, as can be observed, they are very well correlated since the coefficient of determination (R^2) is 0.9571. This result is rather logical since when the incident solar radiation, being the motive power of the thermosiphonic phenomenon, is higher, the temperature difference between the water inlet and outlet also increases. The equation describing the relation between them is the following:

$$\Delta T = -1.02\text{x}10^{-5}(G)^2 + 0.02579(G) - 1.63097 \qquad (2)$$

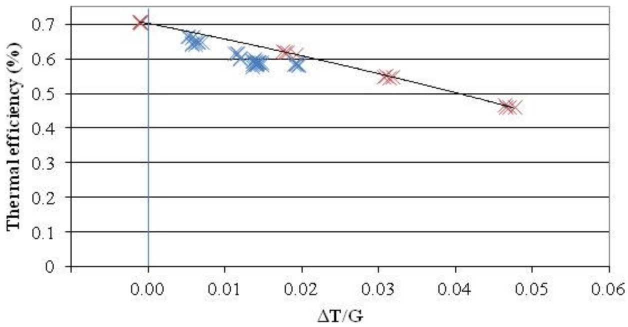

Fig. 2 Efficiency of the solar collector according to EN12975 and under thermosiphonic operation

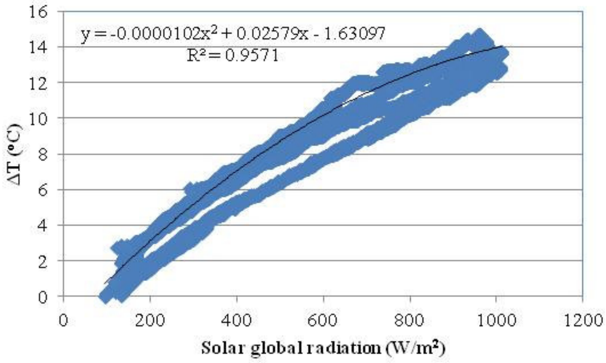

Fig. 3 Correlation of the solar global radiation to the temperature difference of the water in and out of the collector

As can be seen from Fig. 3, quite substantial temperature differences of the order of 15°C are developed in the collector, because of the action of solar radiation. The higher values, as expected, occur at the higher radiation input. It should be noted that by heat rejection the temperature in the storage tank was kept constant (to within 5-6°C) throughout the day.

The results correlating the solar global radiation (G) with the water mass flow (m) are presented in Fig. 4. It can be observed that they are also very well correlated since the coefficient of determination (R^2) is 0.9698.

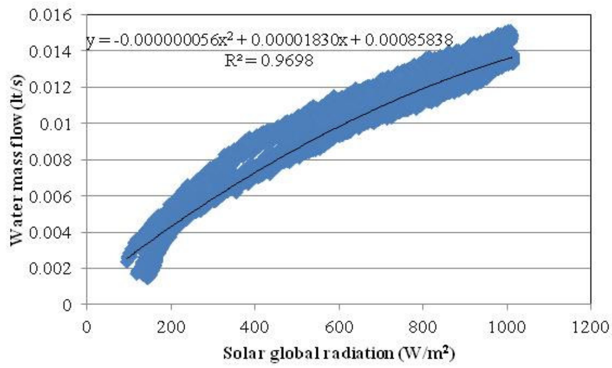

Fig. 4 Correlation of the solar global radiation to the water mass flow

From this result, it can be concluded that this water mass flow, which is naturally created from the temperature difference of the water at the outlet and the inlet of the collector (thermosiphon phenomenon), is directly correlated to the amount of the incident solar radiation on the collector. The equation describing the relation between them is the following:

$$m = -5.6x10^{-8}(G)^2 + 0.00001830(G) + 0.00085838 \quad (3)$$

As can be seen from Fig. 4 a flow rate of about 0.015 lt/s is created by the thermosiphonic effect at the higher radiation levels. By using the collector area of 1.36m^2, this gives a value of 0.011 lt/s/m^2, which is about half the flow rate specified by EN 12975 for testing the solar collectors (0.02 lt/s/m^2). This explains the slightly lower performance of the collector operating thermosiphonically shown in Fig. 2.

The results correlating water mass flow with the temperature difference between the inlet and the outlet water of the collector are depicted in Fig. 5. As can be observed they are also very well correlated since the coefficient of determination (R^2) is 0.9167. The equation describing the relation between them is the following:

$$m = 3.7x10^{-6}(\Delta T)^2 + 0.00096(\Delta T) + 0.0018962 \quad (4)$$

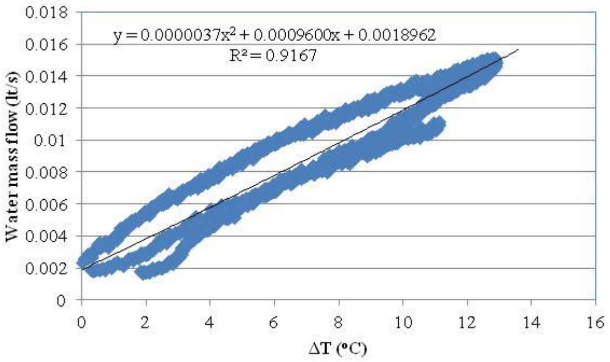

Fig. 5 Correlation of the water mass flow to the temperature difference of the water in and out of the collector

As expected the higher temperature differences create higher flow rates and vice versa. Both values depend on the input power, which is the solar radiation, so the higher values correspond to the higher values of solar radiation input on the collector.

X. Conclusions

This work constitutes the first preliminary data of a research project currently in process in Cyprus, which aims to gain deeper understanding of the 'thermosiphonic phenomenon' and the identification of the key parameters affecting it.

Specifically, a special test rig was set up and equipped with all sensors necessary to measure all parameters that are most likely to affect the 'thermosiphonic phenomenon'. All tests were conducted according to ISO 9459-2: 1995(E). The system was able to operate in various weather and operating conditions and could accommodate the change of inclination of the collector. Initially, the solar collector was tested according to EN12975-2: 2006 in order to determine the thermal performance at a flow and operation conditions specified by the standard. Subsequently, the efficiency of the collector operating thermosiphonically was calculated based on quasi-dynamic approach.

Finally, a series of correlations were attempted using the preliminary data acquired when the collector is operating thermosiphonically for the temperature difference of the water at the outlet and the inlet of the collector, the solar global radiation and the water mass flow.

The results of the data analysis showed that these parameters are very well correlated between them since the coefficient of determination (R^2) is over 0.91 in all cases. These results are very interesting since they give initial inside information of the relation between some of the main parameters that are most likely to affect the thermosiphonic phenomenon. The work is ongoing and the objective is also to find how the collector inclination and the distance between the top of the collector and the bottom of the storage tank affect the performance of the system. This work will lead to the suggestion of a new test procedure suitable for thermosiphonic units.

XI. Acknowledgment

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XIII. Biographies

Soteris Kalogirou was born in Trachonas, Nicosia, Cyprus on November 11, 1959. He is a Senior Lecturer at the Department of Mechanical Engineering and Materials Sciences and Engineering of the Cyprus University of Technology, Limassol, Cyprus. He received his HTI Degree in Mechanical Engineering in 1982, his M.Phil. in Mechanical Engineering from the Polytechnic of Wales in 1991 and his Ph.D. in Mechanical Engineering from the University of Glamorgan in 1995. In June 2011 he received from the University of Glamorgan the title of D.Sc. He is Visiting Professor at Brunel University, UK and Adjunct Professor at the Dublin Institute of Technology (DIT), Ireland. For more than 25 years, he is actively involved in research in the area of solar energy and particularly in flat plate and concentrating collectors, solar water heating, solar steam generating systems, desalination and absorption cooling.

He has 41 books and book contributions and published 264 papers; 109 in international scientific journals and 155 in refereed conference proceedings. Until now, he received more than 4000 citations on this work and his h-index is 35. He is Deputy Editor-in-Chief of Energy, Associate Editor of Renewable Energy and Editorial Board Member of another eleven journals. He is the editor of the book Artificial Intelligence in Energy and Renewable Energy Systems, published by Nova Science Inc., co-editor of the book Soft Computing in Green and Renewable Energy Systems, published by Springer and author of the book Solar Energy Engineering: Processes and Systems, published by Academic Press of Elsevier.

Gregoris Panayiotou was born in Limassol, Cyprus on February 18, 1983. He graduated from the Technological Educational Institute of Athens first of his class as an Energy Technology Engineer in 2007. He had his MSc in Energy in Heriot-Watt University, Edinburgh where he graduated in 2008 with Distinction.

He is currently employed at Cyprus University of Technology as a Research Associate in a nationally funded project concerning the study and the deeper understanding of the thermosiphonic phenomenon that occurs in solar water heating systems that operate thermosiphonically.

In the past he had also worked in two research projects. The first project was funded by the Research Promotion Foundation of Cyprus and concerned the categorization of buildings in Cyprus according to their energy performance. The second project concerned the application and evaluation of advanced absorber coatings for parabolic trough collectors.

The main simulation tool he had used in most of his work is TRaNsient SYstem Simulation (TRNSYS) while he had also worked with HOMER and PVSyst.

He currently has 9 Journal publications and 12 Conference publications and his special fields of interest include wide range applications of Renewable Energy Sources systems and Energy Efficiency in buildings.

Georgios Florides is a Senior Lecturer in the Department of Mechanical Engineering and Materials Science and Engineering. He received his basic degree in Mechanical Engineering from the Higher Technical Institute and he was awarded an MPhil and a PhD by Brunel University, London, UK. He was employed by the Higher Technical Institute from 1975-2007 in various posts, in the Mechanical Engineering Department and in the Engineering Practice Department. He used to teach the theory and practice of Welding, Machine-shop, Bench-fitting and Plumbing.

His research activity focuses on the topic of Energy which includes studies and analysis of the energy requirements of buildings, measures to lower building thermal loads, design of LiBr-water absorption machines, modelling and simulation of absorption solar cooling systems and earth heat exchangers and heat pumps. He also studies the thermal behaviour of reptiles and scientifically constructs models of extinct animals.

Yiannis Vassiades was born in Nicosia, Cyprus. He graduated from the Mechanical Engineering department of the University of Manchester Institute of Science & Technology (UMIST) and he was awarded an honorary Bachelor's of Science degree. He continued his studies in the field of Refrigeration & Air-Conditioning at King's College London (KQC) and acquired a Master's of Science degree.

His previous professional experience includes working as a consultant Mechanical Engineer in both the private and the public sectors. He also worked in the mechanical contracting sector focused in the building construction industry.

Today, he holds the position of a Standards Officer at the Cyprus Organisation for Standardisation – CYS, promoting the application of European and international standards by Cyprus businesses. Frequently, he represents Cyprus in European Technical Committees of the European Organisation for Standardisation (CEN) for matters related to Mechanical Engineering. In addition, he acts as the Secretary of the national standardisation Technical Committee CYS/TC 13 "Thermal Solar Systems".

Thomas Parissis was born in Athens, Greece, on September 4, 1982. He holds a Diploma in Mining Engineering and Metallurgy from the National Technical University of Athens (NTUA) and an MSc in Metals and Energy Finance from Imperial College London for which he was awarded a scholarship by Eugenides Foundation in Greece.

During his career he held various positions in both production and commercial departments in industrial companies (ETEM S.A., Paperpack Tsoukaridis S.A.) and also offered consulting services regarding business development. At the moment he is working for RTD TALOS LTD as a Project Manager offering consulting and project management services to SMEs. In September 2011 he published his first book titled "Mine Expansion and Financial Implications" (ISBN 978-3845405643).

His special fields of interest include Energy, Mining, Metallurgy and Oil & Gas.

Alexandros Michaelides was born in Nicosia, Cyprus, on January 17, 1966. He holds a diploma in Mining Engineering and Metallurgy from the National Technical University of Athens (NTUA) and a Ph.D. degree in the sector of Metallurgy and Materials Technology of NTUA. During the period of 1990-1995 he worked as a researcher in the Laboratory of Physical Metallurgy of NTUA where he participated in a number of National and European research programs. Dr. Michaelides has presented his research work in numerous international conferences and he is the author/co-author of more than 15 research papers.

His employment experience includes the Cyprus Institute of Technology (CIT) where he was holding the position of the General Co-ordinator having under his supervision all of CIT's activities and RTD TALOS LTD, a development organisation dealing with technology and innovation issues, which was established by Dr. A. Michaelides in 2000.

His special fields of interest include Materials, Technology Transfer and Innovation.

Jan Erik Nielsen was born in Denmark on July 12, 1957. He graduated from the Danish Technical University in 1981. His employment experience include the Danish Technical University, the Danish Technological Institute, the private consultant company PlanEnergi and his own company SolarKey Int..

His special fields of interest are test methods, standards and certification for solar thermal systems and components and large scale solar thermal systems.

He is currently Operating Agent for IEA-SHC Task 43 "Solar Rating and Certification" and for IEA-SHC Task 45 "Large solar systems" (IEA-SHC is International Energy Agency – Solar Heating and Cooling).