# Enhancing Reliability of Empirical Temperature Measurement of a Solar Water Heater System with a Temperature Data Logger

**Oguche, Emmanuel Enemona[1], Garba, Isa[2] & Jimoh, Mohammed Tajudeen[3]**
[1]Industrial Training Fund - Industrial Skills Training Centre, Dorayi-Kano, Nigeria.
emmimd@gmail.com: 08069353997.
[2]Nigeria Defense Academy, Kaduna - Nigeria.
isagar2051@yahoo.com: 08065418536
[3]Department of Mechanical Engineering, Bayero University, Kano - Nigeria.
mtjimoh.mec@buk.edu.ng: 09031754392

## Abstract
*The quality and reliability of empirical results generated during any study can be established by how closely related those results obtained are, if the experiment is repeated severally within a given space of time. Such tasks could be herculean and laborious if they are required to be performed manually. Results obtained from such tedious measurement may be prone to a lot of human errors, especially where a large volume of data is required to be measured for a longer duration. Hence, deployment of Data Logger for empirical studies could help eliminate such errors and difficulties thereby, enhancing accuracy and reliability of experimental results. The Met Scientific System International (MSSI:MS08) Data Logger was suitably deployed for a 200 litre/day installed capacity solar water heater system for Good Pasture Clinic and Maternity, located at N0 6 Citta Avenue, Nomansland, Kano, Nigeria. A seamless analysis of the temperature drops in the installed 200 litre/day solar water heater system was achieved with little or no human presence using the MSSI:MS08 Data Logger. The MSSI:MS08 Data Logger deployed at the Good Pasture Clinic and Maternity, provides holistic temperature trend monitoring of all input point of measurement throughout the day and night hours. This help in providing a true picture of temperature drops within the solar water heating system as compared to those obtained by simulation which only shows defunct values at night due to non-availability of solar irradiation. The ease of measuring multiple empirical variables data points makes the use of Data Logger more potent as data measuring instrument.*

**Key Words:** Data Logger, Solar Water Heater, Measurement, Empirical Data, Reliability and Calibration.

## Introduction
Data capturing and monitoring of any sort of variables can be an enormous task for researchers, especially, where variables are to be measured real time and remotely under harsh environment. Another very important consideration is the quantity and quality of data to be measured which can greatly affect the quality and reliability of empirical results, if a researcher requires to take measurement readings consistently, for every minute of the day for a week or more. This is not going to be easily done using manual data capturing techniques. The reason is very obvious due to the frequency of measurement and the large number of data samples to be measured in real time within the specified period. Fatigue as well as other human factors can result in errors and that can affect the quality and reliability of the results generated.

Various methods and devices such as manual readings, chart recorders or data loggers are available for retrieval of information (Badhiye *et al.*, 2011). Data logging are an important aspect in a modern-day measurement and instrumentation system. Almost all the industrial process requires data logging (Singh and Thakur, 2019). Deployment of automation such as the use of digital Temperature Data Logger can help solve to a large extent, researchers' nightmare of remotely taking quality and reliable data. Hence, the use of a digital data logger, thermometer probe(s), immersed in a thermal buffering fluid as the preferred device for temperature monitoring can enhance effective, as well as provide accurate tracking on temperature history (Chojnacky *et al.*,2015).

Environmental field measurements can be obtained by using the Compact Humidity Logger and Thermal Data Logger (Nugroho *et al.*, 2007). The measurement of temperature by using appropriate sensors and controllers is not only important in environmental or weather monitoring but also crucial for many industrial processes (Aneja *et al*., 2014). Worthy of note is the important role temperature measurement and monitoring play in today's industries, hospitals, science and medical based research institutes, laboratories, aviation sector, meteorological stations, and other critical sector where monitoring of thermal energy is expedient. The use of digital instruments such as temperature probe and temperature data logger for efficient and effective as well as seamless measurement and monitoring cannot be overemphasized.

A data logger is an electronic device with digital processor that combines analog and digital measurements with programming methodology to sense temperature, relative humidity and other parameters such as voltage and pulse (Badhive *et al.*, 2011). Basically, they provide the monitoring and logging of data by using transducers, computer and sensors (Singh & Thakur, 2019). They are also equipped with a large storage capability which enables them to record data over a long period, depending on the data size of the variable(s) to be measured and the frequency of measurement (1second, 1minute, 5minutes, 15minutes, 30minutes and 1hour intervals) as the case may be. Though the smaller the interval of measurement, the more the data sample collected. Such large data may be very laborious to treat. The ability to clearly present real time results with sensors and probes able to respond to parameters that are beyond the normal range available from most traditional equipment makes them an invaluable tool for collection and analyzing of experimental data (Badhiye*et al.*, 2011).

Apart from having the ability to decode sensor measurement and seamless storage capacity, recent models of this automated device also come with capabilities that can easily analyze data, present results in graphical display and clearly show trends that can aid researchers make inferences on a particular study. These capabilities make data logger very suitable for deployment in thermal storage experiment where residence time of thermal storage facility is critical as in the case of a solar water heater thermal storage. Data loggers could simplify temperature monitoring during transportation and storage of variety of perishable foods, including other seafood products, meat and poultry products and produce (Drake *et al.*, 2009).

**Literature Review**

The consideration of quality assurance, reliability of data and the ease of data capturing has motivated a lot of researches across different fields of science and engineering on the need to leverage on automation in data capturing. Ariyawiriyanan *et al.*, (2013) deployed a portable data logger station YOKOGAWA Datum-Y, XL100 to measure temperature inputs, outputs and ambient temperature from 9.00-16.00 Hours throughout the day during a study on "Thermal efficiency of solar collector made from thermoplastics". Goyal and Malhotra (2012) in their survey on data logger gave a brief introduction about data logger system as a system that takes input real-time from sensors and store automatically on storage memory. Okwudibe and Akinloye (2017) presented the design and simulation of a temperature data logger with the advantage of provision of large storage facility to store bulk data which can be viewed or deleted at any time.

Haque and Hossain (2021) proposed a model that integrates hardware and software of a smart solar-data logger system (SSDLS) for photo voltaic (PV) designers. Like most basic data logger, the SSDLS systems senses DC voltage, temperature of the PV array, and display real-time data on an LCD as well as store same on its memory. However, this model requires minor modifications to allow for automatic data uploading to the web and an external DC source to bias the controlling unit. Similarly, Effendi *et al.,* 2018, have developed a data logger to evaluate area of solar panel. In the design, current as well as voltage sensors were integrated on the data logger board to measure parameters that affect the efficiency of photo voltaic (PV) system. Prajapati and Tiwari (2020) performed a study on "a review on photo voltaic monitoring and data logging system" where the designed data logger records the value of real time voltage, current, power and energy related to two PV solar panels simultaneously. It however, did not consider effect of weather conditions in the design and development of the data logger and how its working in different weather condition could be examined.

Panagopoulos and Argiriou (2022), proposed a design and testing of low-cost data acquisition system for solar thermal collector. The proposed system is based on the ESP32 board, which uploads measurement data to a web application's back-end that stores the data to a MySQL database. The results demonstrated that the proposed system can acquire high-quality measurements and provide real-time data access. Similarly, Murade *et al.,* 2022, focuses on constructing a low-cost, user-friendly, and dependable data logger and monitoring system based on the ESP 32 microcontroller for a pico solar home system in a rural location of a developing country. Data are stored on the SD card as well as on a local HTML webpage. The logger also possesses an android mobile app capability for real time display and text message alert for maintenance if the battery voltage goes beyond a threshold value. Asif *et al.,* 2016, based his design and development of a data logger on IEEE 802.15.4 and GSM Technology with a 32bit microcontroller as a central processing unit. He adjudged the wireless data logger to be cost effective, fast and able to perform in a wild and short rang. This makes it beneficial for research and environmental monitoring.

Bayhan and Turhan (2021) manufactured and tested a low-cost temperature and relative humidity data logger prototype in a case building at Atılım University in Ankara/Turkey. The developed data logger is compared with the HOBO-U12 data logger during four days. The results show that the cost of the data logger can be decreased by approximately 82%. In comparison, the accuracy of the data is 97% and 96% for temperature and relative humidity, respectively, compared to the commercial data logger. The deployment of data loggers for temperature and humidity monitoring is gaining prominence in food and logistic services. Malls, ware houses and logistic companies are now more than ever are leveraging on the benefits of using data logger for real time effective monitoring of temperature, humidity and other important parameters necessary for quality assurance of perishable products. Mattolia *et al.,* 2009 have designed, developed and tested a flexible tag data logger for improving food and goods logistics during transport, storage and vending. The miniaturized device integrates three sensors (temperature, humidity and light) and a microcontroller for its operation.

## Methodology

### *Materials*

A 200 Litre ($0.2m^3$) per day solar water heating system comprising of two collectors; a flat plat collector and an evacuated tube collector with an underground thermal storage tank was installed at Good Pasture Clinic and Maternity, Nomansland Kano, to meet the daily hot water demand of the hospital. To study the thermal behaviour of the installed system at the hospital, a digital temperature data logger (MSSI:MS08) with $PT_{100}$ (3-Wire) temperature probes were installed for a seamless monitoring of the thermal behaviour of the system.

### *Data Logger Description*

Data loggers are electronic devices with capabilities of monitoring pressure, temperature, humidity, voltage and current at a varying degree. These capabilities make its usage suitable for deployment in almost all fields of science and human endeavours. A complete data logging application generally requires most of the elements/components as listed below (Badhive*et al.*, 2011):

i. Nature of the experimental variables to be measured;
ii. Sensors to be used;
iii. User Interface;
iv. Software.

Badhive *et al., (*2011) gives a detailed description of a data logger process as shown in Figure 1 below:

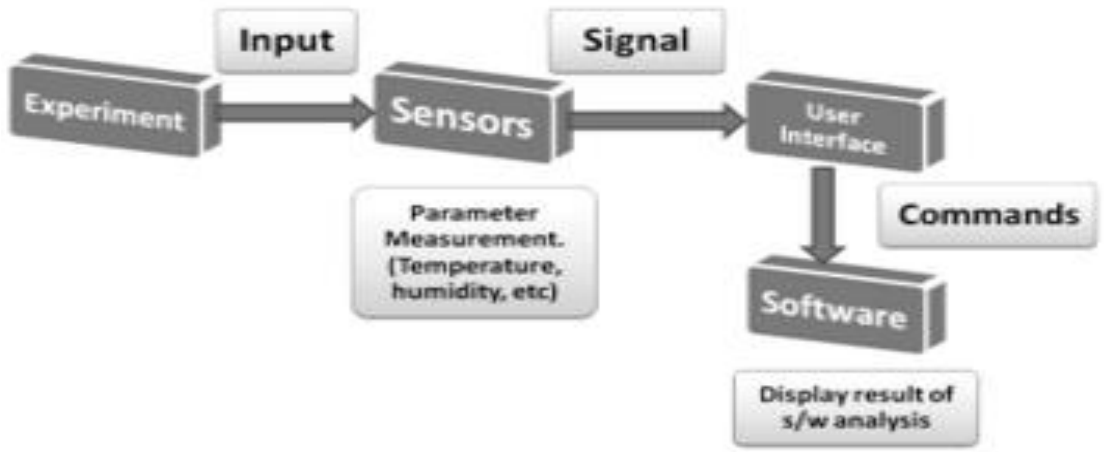


**Figure 1: A Data Logger Process (Badhive et al., 2011)**

Data loggers as an electronic instrument, records measurements at set intervals over a period of time (Onset, 2016). Data loggers are typically compact, battery-powered devices equipped with an internal microprocessor, data storage, and one or more sensors which can be deployed indoors, outdoors, and underwater, and can record data for up to months at a time, unattended (Onset, 2016).

There are 3 main types of data loggers: stand-alone USB data loggers, web-based data logging systems, and Bluetooth Low Energy data loggers. The device has three different user interfaces, such as SD card slot, data logger and mini-USB (Kumar *et al.*, 2020). Such interfaces have made the equipment provide benefits to various areas by facilitating the obtainment of large volumes of data in real time, as well as the transfer and storage of those data (Da Cunha, 2015).

### *Calibration of Data Loggers*

A data logger's importance in measuring and recording various parameters cannot be overemphasized as it helps serve in different capacities, from accuracy to reliability and timely manner of materials investigation (Essien *et al.*, 2020). It is also important to perform individual calibration because most probes do not meet the acceptable validity of ±0.1 ◦C or their manufacturer claimed validity (Versey *et al.*, 2011). The efficacy of a data logger can be maximized optimally with proper calibration.

For calibration purpose, the data loggers must be checked against at least 3 known temperatures, but better with more, and the recorded temperatures from the data loggers must be compared against temperatures concurrently read from a certified thermometer (Girondot *et al.*, 2018). MSSI:MS08 Temperature Data Logger with the RTDs temperature probes (sensors) were calibrated at the instrument calibration laboratory of Alifig International Ltd, Abuja, before deployment to site for use.

***The Met Scientific System International (MSSI) Data Logger***

The MSSI data logger (MS08TDL version) is a rugged electronic device with multiple measuring channels, capable of measuring various variable points and storing same on its large internal memory. It compares favourably with other digital data logger. This version as shown in figure 3 below is a ten channel data logger suitable for measuring multiple temperature probe input. It comes with two options of powering it: by using a solar powered battery or by simply using a 12V adaptor from an AC source. It provides users with options of determining the intervals at which data can be recorded and stored. For instance, an experiment requiring one second interval of data is collected and stored real time which implies for every 1hour 3600 data samples are recorded. Researchers have the liberty to set their predetermined interval of measurement depending on the study requirement they are embarking on.

The memory capacity of an MSSI data logger can accommodate experimental results (data/seconds) for up to six months or more without human presence at site while for interval of measurement of data/hour, storage can last for years without erasing previous data stored on its memory. A temperature data logger increases the amount of temperature data gathered at a thermal feature and the logging interval and logger memory determines the number of visits per year (Heasler *et al.*, 2009). As a result of the large volume of data that are generated using data logger, data ‘‘cleaning’’ is critical to ensure data are accurate and reliable for decision-making purposes (Chapin *et al.*, 2014). A data Logger Download Manager is a software interface compatible for use in retrieving data on the MSSI data logger unto a computer device. This is done via various mean such as the USB cable. The software is user friendly and gives a variety of options to have multiple project sites on one logger. Figure 2 shows a computer screenshot outlook of the MSSI data logger download manager software.

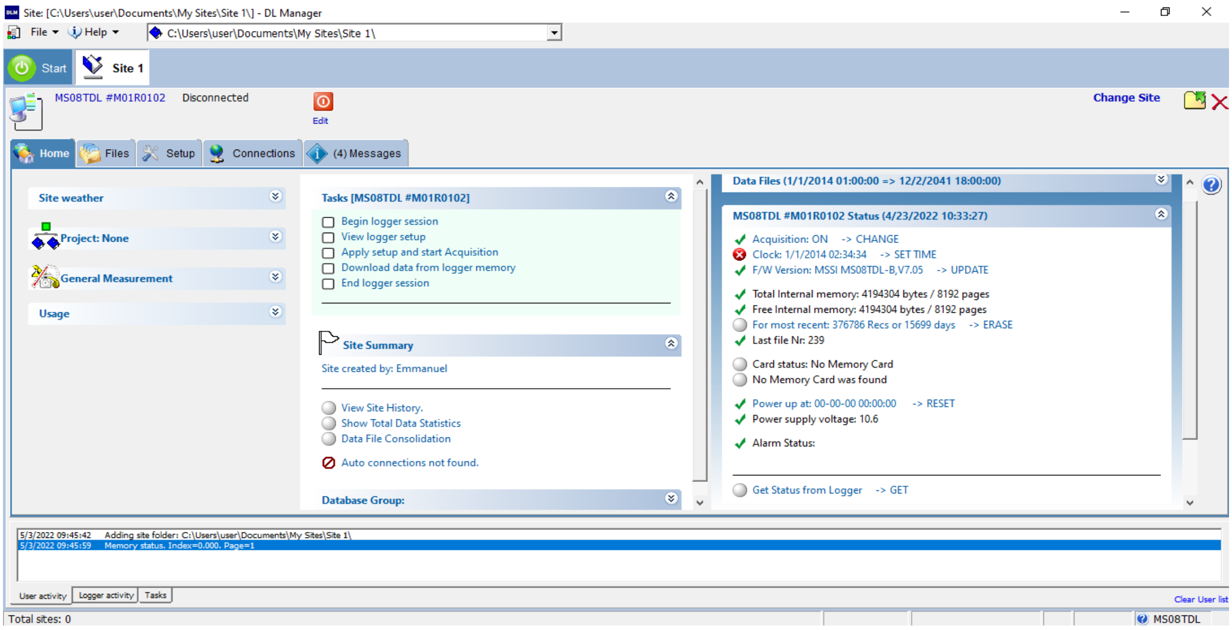


**Figure 2. Screen outlook for Data Logger Manager**

Some versions of the MSSI loggers have capability of transmitting results from site location to based location via any of these means; a dial up call communication system, an Ethernet network connection system, the internet or using a unidirectional 'Yaggi' antennal system. These capabilities allow MSSI data loggers collect and transmit real-time data remotely. The following are basic properties of an MSSI data logger:

- Create a new site and configure its properties
- Create a local RS-232 connection
- Internal GSM/GPRS modem' or 'Internal Ethernet'

Some data loggers interface with a personal computer, and use software to activate it and to view as well as analyse the collected data, while many others have a local interface device (keypad, LCD) and can be used as a stand-alone device (Tripathi*et al.*, 2017). Other newer models have LCD screens that provide operating information, while others have simple light indicators (Onset, 2016). The MSSI data logger on the other hand, have both the computer interactive interface (with either USB cable port or Ethernet network port) as well as keypad and LCD screen for manual monitoring and navigation purpose(s). Figure 3 below shows a typical MSSI data logger.


**Figure 3: Met Scientific System International (MSSI:MS08) Data Logger**

***Resistance Temperature Detectors (RTD'S)***

$PT_{100}$ (3-Wire) Temperature Probes are categorized as RTD's Sensor. They offer excellent and accurate measurement of variables over a wild rang of temperature between -200 $^0$C to +850 $^0$C which makes their deployment for this experiment suitable. They can also withstand high temperature and even corrosion when placed in thermal substances. Figure 4 below presents a typical RTD sensor.

**Figure 4: $AT_{100}$ (3Wire) Temperature Probe**

### *Data Collection*

To study the 200litre/day solar water heater system with an underground thermal storage installed at the Good Pasture Clinic and Maternity, Nomansland, Kano, Nigeria, various RTD's temperature probes were connected at different inlet points to adequately measure and monitor the temperature trend of the solar water heating system. The various temperature input points measured using the $AT_{100}$ (RTD 3Wire) temperature probe includes:

i. Cold water tank temperature
ii. Flat plat collector
iii. Evacuated tube collector
iv. Underground thermal storage tank
v. Ambient temperature

The MSSI data logger works well with the RTD temperature probes (3 wires). Figure 5 gives a schematic diagram of the experimental setup of the system.

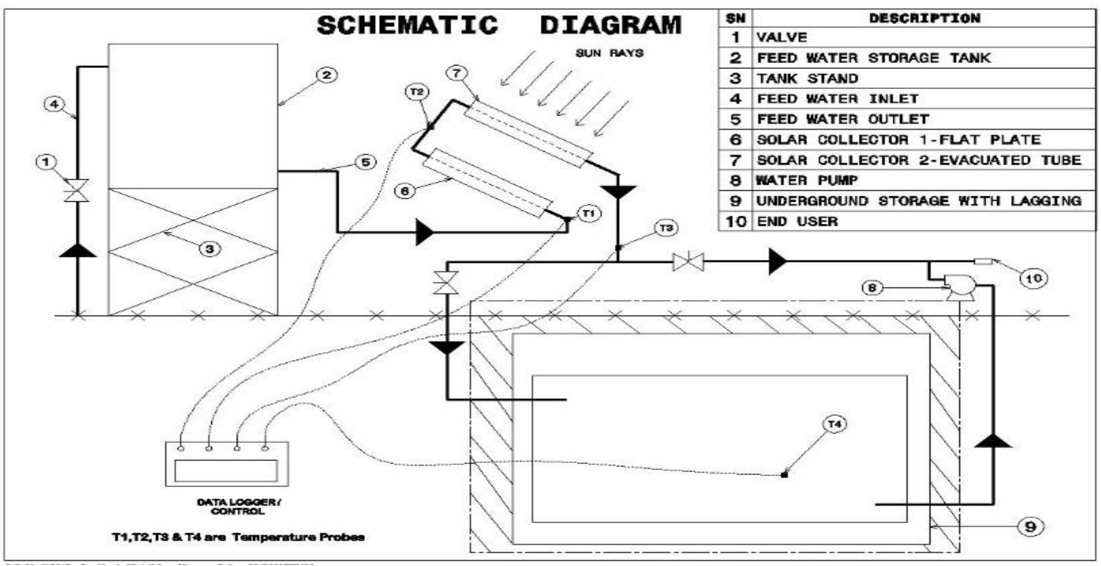


**Figure 5: Schematic diagram of the experimental setup.**

Table 1 below gives a brief description of the data capturing equipment used for the experiment.

**Table 1: Data Capturing Equipment**

| S/N | Data Capturing Device | Description | Importance |
|---|---|---|---|
| 1 | Met Scientific System International (MSSI) Data Logger | • Powered using a 12V DC (battery) supply or an AC supply with a 6-12V adaptor.<br>• Wild rang storage capability of between 118days/Seconds to 11260 days/Hour | • Real time data storage.<br>• Seamless download of stored data.<br>• Real-time data displayed on the LCD display screen for manual recording. |
| 2 | $PT_{100}$ (3-Wire) Temperature Probe. | • $PT_{100}$ fall under Resistance Temperature Detectors (RTD's). | • Measures a wild rang of temperature between -200 $^{0}$C to +850 $^{0}$C.<br>• Can withstand high temperature and even corrosive substances. |
| 3 | Solarimeter | • It is a type of Pyranometer, | • Measures combined direct and diffuse solar radiation. |

**Results and Discussions**

An experimental sample result from one of the tests conducted on the 200 Litre/day installed capacity solar water heater system on the Good Pasture Clinic and Maternity, as well as those obtained from simulation are presented in tabular and graphical format as shown in Table 2 and Figure 6 respectively.

**Table 2: Solar Collectors (Simulation/Empirical) Temperature Gain Comparison for Recommended Day – April 15, 2021 at Good Pasture Clinic, Kano.**

| Time (Hr) | Amb. Sim. Temp. ($^{0}$O) | Amb. Exp.Temp. ($^{0}$O) | CW Tank Temp. ($^{0}$O) | FPC Sim.Temp. ($^{0}$O) | FPC Exp.Temp. ($^{0}$O) | ETC Sim.Temp. ($^{0}$O) | ETC Exp.Temp. ($^{0}$O) |
|---|---|---|---|---|---|---|---|
| 1 | 28.62 | 33.05 | 32.55 | 28.62 | 34.51 | 28.62 | 62.18 |
| 2 | 27.55 | 32.71 | 30.12 | 27.55 | 33.45 | 27.55 | 59.91 |
| 3 | 26.45 | 32.49 | 29.41 | 26.45 | 32.54 | 26.45 | 55.4 |
| 4 | 25.35 | 32.39 | 30.07 | 25.35 | 32.72 | 25.35 | 54.72 |
| 5 | 24.25 | 31.7 | 28.83 | 24.25 | 31.69 | 24.25 | 53.04 |
| 6 | 23.15 | 32.45 | 28.41 | 23.15 | 31.4 | 23.15 | 50.3 |
| 7 | 22.62 | 32.82 | 28.43 | 17.16 | 31.16 | 19.01 | 48.57 |
| 8 | 24.20 | 32.47 | 28.42 | 25.76 | 30.32 | 32.40 | 46.92 |
| 9 | 27.02 | 32.08 | 29.74 | 30.77 | 30.83 | 42.96 | 40.27 |
| 10 | 29.70 | 32.46 | 30.46 | 37.22 | 32.23 | 58.02 | 40.65 |
| 11 | 32.23 | 33.99 | 32.8 | 45.95 | 37.09 | 76.30 | 47.11 |
| 12 | 34.65 | 40.81 | 33.82 | 48.86 | 38.15 | 73.66 | 59.7 |
| 13 | 36.22 | 43.69 | 34.04 | 52.01 | 41.86 | 84.15 | 66.48 |
| 14 | 37.55 | 45.02 | 34.49 | 52.65 | 42.41 | 78.87 | 70.45 |
| 15 | 38.36 | 45.88 | 35.72 | 50.32 | 45.23 | 75.00 | 75.28 |
| 16 | 38.38 | 44.64 | 36.23 | 47.17 | 48 | 67.62 | 79.21 |
| 17 | 37.80 | 44.23 | 36.21 | 40.70 | 45.29 | 51.06 | 73.13 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 18 | 36.49 | 42.68 | 36.55 | 35.35 | 45.31 | 43.17 | 64.59 |
| 19 | 34.76 | 39.6 | 36.68 | 36.23 | 45.31 | 37.03 | 59.34 |
| 20 | 33.25 | 36.91 | 36.5 | 33.25 | 40.89 | 33.25 | 53.28 |
| 21 | 31.95 | 36.76 | 34.94 | 31.95 | 39.37 | 31.95 | 53.94 |
| 22 | 30.69 | 33.62 | 33.84 | 30.69 | 37.77 | 30.69 | 51.74 |
| 23 | 29.44 | 34.37 | 32.7 | 29.44 | 36.33 | 29.44 | 51.23 |
| 24 | 28.20 | 31.3 | 30.82 | 28.20 | 34.96 | 28.20 | 49.95 |

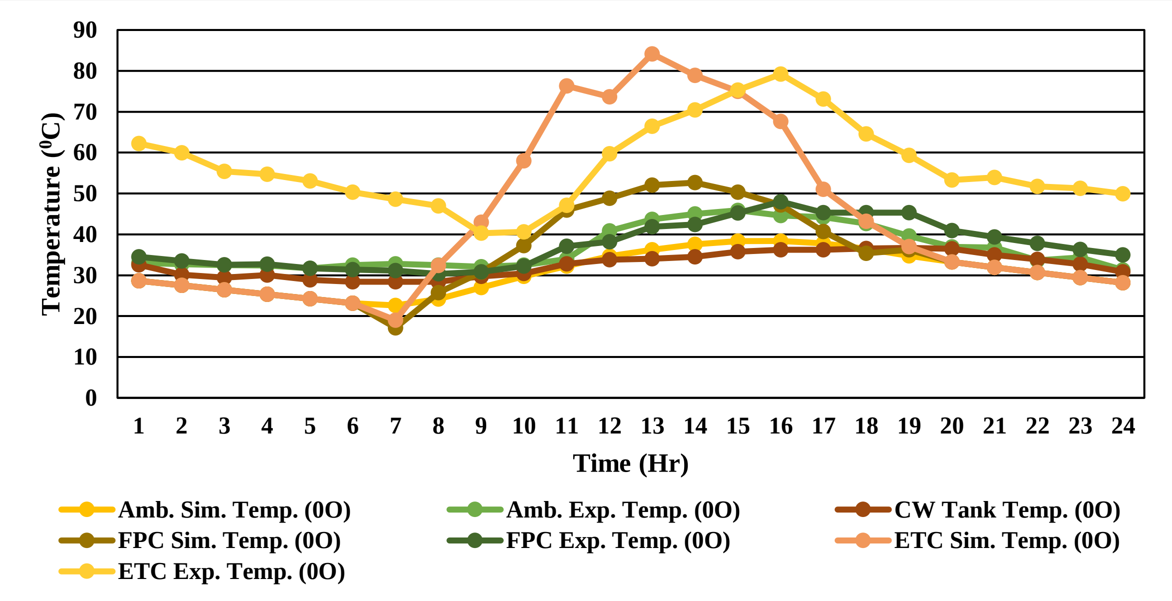


**Figure 6: Simulated and Experimental Collectors Temperature Performance gain comparison for recommended day –April 15, 2021 at Good Pasture Clinic, Kano.**

Table 2 as corroborated by figure 6 presents simulation and physical experimentation (Sim. and Exp.) temperature profile of the solar water heater system (for recommended day April 15, 2021). The ambient temperature (Amb. Temp.), cold water tank temperature (CW Tank Temp.), flat plat collector temperature (FPC Temp.) and evacuated tube collector temperature (ETC Temp.) for both simulation and physical experimentation are presented for analysis and comparison. The ambient temperature data shows similarity in terms of temperature gradient however, the experimental data were slightly higher. Similarly, there is similarity in the temperature gradient of the flat plat collector (FPC) and evacuated tube collector (ETC) for simulation and physical experiment. Temperature begins to rise from sunrise and begins to rapidly drop at sunset. However, the simulation values for FPC and ETC before sunrise and after sunset are defunct values which are also the same for the simulation ambient temperature. The simulation can only predict results adequately within period of solar irradiance availability (6 am to 6 pm). Results outside these periods (6 am to 6 pm) are assigned defunct reading for all the variables. This may explain the reasons behind why many research works on solar water heater system takes temperature measurement only within the period of sun shine (7am to 6 pm). The MSSI data logger could give a true picture of how temperature drops within the system and to what extent. Hence, deployment of a temperature data logger like the MSSI Data Logger can help researchers understand the time it will take for temperature to drop in any thermal energy study.

The simulation temperature performance of the collectors (FPC and ETC) was slightly higher than those of the physical experimentation. However, there is better performance of the experimental ETC in terms of how temperature of hot water drops. This is so owing to the fact that it has a well lagged manifold storage system.

Data logger provides researchers a holistic monitoring and storage capabilities of variables round the clock. This advantage can ensure quality assurance and reliability of research findings and hence, providing near perfect result outcome.

## Conclusion

The ability to measure real time, present data on liquid crystal display (LCD) screen as well as store data on a large memory for immediate or later use has made the deployment of data logger an essential scientific measurement and monitoring tool. Deployment of MSSI Data Logger with temperature probes for thermal performance monitoring of the 200Litere/day solar water heater system installed at a medical facility (Good Pasture Clinic and Maternity, Kano-Nigeria) has proved effective. Rise in temperature as well drop in temperature of the collectors was adequately captured throughout day and night hours. Such day and night measurement is almost impossible to achieve with manual data collection technique where data collection is prone to a lot of human errors and difficulties.

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