IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Instrumentation Mesure Métrologie
Vol. 19, No. 6, December, 2020, pp. 471-479
Journal homepage: http://iieta.org/journals/i2m

Effects of the Rock-Bed Heat Storage System on the Solar Greenhouse Microclimate

Salah Bezari[1,2*], Sidi Mohammed El Amine Bekkouche[2], Ahmed Benchatti[1], Asma Adda[3], Azzedine Boutelhig[2]

[1] Laboratory of Mechanics, Department of Mechanical Engineering, University of Laghouat, Laghouat 03000, Algeria
[2] Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, Ghardaïa 47133, Algeria
[3] Laboratory of Biomaterials and Transport Phenomena, University of Medea, Medea 26000, Algeria

Corresponding Author Email: bezarisalah@uraer.dz

https://doi.org/10.18280/i2m.190608

Received: 19 September 2020
Accepted: 26 November 2020

Keywords:
greenhouse, measurement, microclimate, rock-bed, solar heating system

ABSTRACT

The Mediterranean area is characterized by intense radiation generating high temperatures during the day in the greenhouse and low temperatures during the night. The temperature gap problem between the daytime and the nocturnal period which characterizes the region requires the use of greenhouses with a thermal storage system. A greenhouse equipped with a sensible heat storage system using a rock-bed, was compared to a witness one, under the same climatic conditions. Measurements were performed on the microclimate parameters of both greenhouses, such as temperature and relative humidity. Our work is based on an experimental analysis of greenhouse microclimate and evaluating the evolution of temperature and relative humidity prevailing inside the greenhouse. It has been found that the system efficiency is improved due to the storing of heat in excess during the daytime. This stored energy is used during night. The main obtained results showed that the heat storage system allowed an increase in the air temperature up to 0.9℃ and a decrease of the relative humidity about 3.4% during the night compared to the witness greenhouse. The improvement in the heated greenhouse microclimate during night has a very positive impact on the quality of fruit and yield.

1. INTRODUCTION

Presently, given the rapid population growth and the ever-increasing demand for agricultural products all over the world, greenhouse food production is an additional alternative to meet the growing demand for food throughout the year. Greenhouses are generally characterized as infrastructures with thin transparent glass panels or plastic sheets; they protect the crop by creating a favorable microclimate in different climatic zones. According to Mesmoudi et al. [1], the greenhouse design as well as the cover material characteristics greatly affects the greenhouse energy. The main prevailing factors for greenhouses are: relative humidity, light, temperature and nutrients. These factors must be maintained at optimal levels for crop growth.

Conventional greenhouses face the problem of being very cold at night and overheated during the day. Therefore, it will be difficult to maintain the required indoor environment and obtain good food quality. Heating agricultural greenhouses are the most common use of solar energy in agriculture. Among the heating systems frequently used in greenhouse heating technologies, and applications, are those that use solar thermal energy, which can be stored as latent heat [2], or sensible heat [3]. Many heating thermal storage systems and applications are recommended in the literature [4, 5].

Rocks are among the materials used in most thermal storage systems to heat greenhouses. Singh et al. [6], conducted an experimental study on a heating system filled with 8500 kg rock pebbles under charging and heat retrieval mode. The heat system efficiency of the solar heating and heat retrieval ranged between 36-51% and 75-77%, respectively. An experiment study was conducted in a natural convection solar greenhouse dryer using various sensible heat storage materials (concrete, sand and rock-bed), aimed to know their thermal performance. The dryer system efficiency was indicated to 11.65% with rock-bed [7]. Kürklü et al. [8] studied the heating of a 15m^3 greenhouse covered with PE situated in Turkey by relying on a rock-bed placed underground. The rocks were placed in two insulated and excavated channels and the air (1100 m^3/h) was pushed through the layer of stones. Under winter conditions, the used system can keep the inside air temperature above 10℃. Another work, Bazgaou et al. [9] studied the influence of the same system on Canary type greenhouses. They found during the winter night period, an improvement in the internal air temperature of the greenhouse by 2.6℃. Gourdo et al. [10] studied a comparison between a greenhouse containing a system consisting of a cylindrical tank filled with rocks placed on a floor and a conventional greenhouse without a heating system, the system is able to increase the air temperature in the greenhouse by 1-2℃.

Many researches were used to heat storage in water, among these works we can cite. A work reported by Gourdo et al. [11], used black plastic sleeves filled with water with a capacity of 5.6 m^3 inside a greenhouse covering an area 172 m^2, located at south of Agadir. It is found that, the system improving the nighttime temperature inside the greenhouse by 3.1℃ compared to the control greenhouse. According to Hassanien et al. [12] the system increases the air temperature by 2 to 3℃ and covers more than 35% of the energy used to heat greenhouses.

Ghosal and Tiwari [13] using a system integrated into the greenhouse of the earth to air heat exchanger (EAHE). The advantage of this system is to reduce the mass flow of the incoming air. The coupling between greenhouse heating systems has the advantage of increasing the temperature inside. A comparative study was conducted by Lazaar et al. [14] of two sources of heating in greenhouses (electric heating and solar heating), it was found that the SHS (solar heating system) can increase the air temperature by 2℃ while the EHS (electric heating system) increases it by 4℃. Another type of systems is presented in the study of Bargach et al. [15], they developed a solar flat plate collector to heat a tunnel greenhouse; this system was able to increase the inside air temperature of the greenhouse by 1.2℃ compared to a conventional greenhouse.

There is a large number of PCMs that melt and solidify at a wide range of temperatures, which are used in greenhouses, such as $CaCl_2$ $6H_2O$, Na_2SO_4 $10H_2O$ and paraffin. A new hydroponic greenhouse has been developed by Baddadi et al. [16], it is equipped with a solar air heater system using PCM. They found a night temperature gain of 6℃ of the air inside the greenhouse with two beds filled with LTES compared with conventional greenhouses. In a similar work, Chao et al. [17] studied an active and passive ventilation wall with PCM in greenhouses. Their results were validated using both experimental and numerical methods to justify its advantages over conventional walls. The used PCM can increase the wall's irradiated surface temperature up to 2.01-2.67℃ during the nighttime. Based on the latent heat storage procedure, Öztürk [18] used paraffin wax as PCM to provide the thermal energy needed for a 180 m^2 greenhouse. Energy reached about 4.2% and energy efficiency was up to 40.4%. For their part, Kooli et al. [19] constructed and installed two similar greenhouses with a nocturnal shutter in Tunisia. The first is equipped with a solar heating system using latent heat storage. The experimentally obtained results demonstrate that the differences between nocturnal temperatures inside greenhouses with and without shutter are important.

Recently, sensible thermal storage has been considered as a very promising advanced technology, due to its multiple advantages of ease of application, dependence on renewable resources and preservation of the environment. In addition, the sensible heat storage materials have the advantage of reducing the total cost while increasing the profitability [20]. The thermal conductivity is greater than that of phase change materials [21].

In the current paper, a novel design of a heat storage system was proposed to heat a tunnel greenhouse installed under a semi-arid climate of Ghardaïa region. The objective of this work is to study the thermal performance of this heating system to optimally improve and control the greenhouse microclimate.

This work was structured as follow: an introduction, in a second section we shall present a collection of data from the experiment site as well as the description of two greenhouses and the thermal storage system, presentation of the measuring instruments and synthesis of uncertainty. Significant results have been reported in section 3. Several items were dealt with including preliminary tests related to hygro-thermal behavior between greenhouses, effect of the solar energy on greenhouse microclimate, the performance of thermal storage system efficiency. Finally, the main remarks of this work will be reported in the conclusion which summarizes the main results obtained as well as the studies that can be considered in the future.

2. EXPERIMENTAL SETUP

2.1 Case study and data collection

The continent of Africa has great solar potential, with an average amount of radiant solar energy of about 2400 kWh/m^2 [22]. From the map of the average annual global irradiation received on a horizontal plane (Figure 1), it is clear that Algeria has an important solar potential. The duration of solar radiation overall Algerian lands exceeds 2000 hours per year, and in the Sahara region, it can reach to 3370 hours per year [23].

However, Ghardaïa is a desert region, located in the southern part (32.36° N, 3.81° W), with a semi-arid climate characterized by the more important sunshine duration with a monthly daily average varying from 5 h until 14 h [24]. In addition, the region has an astonishing solar potential, where the cumulative of the direct irradiance at normal incidence and the global solar irradiations recorded, vary from 2100-2200 kWh/m^2 and, 2000-2100 kWh/m^2 respectively.

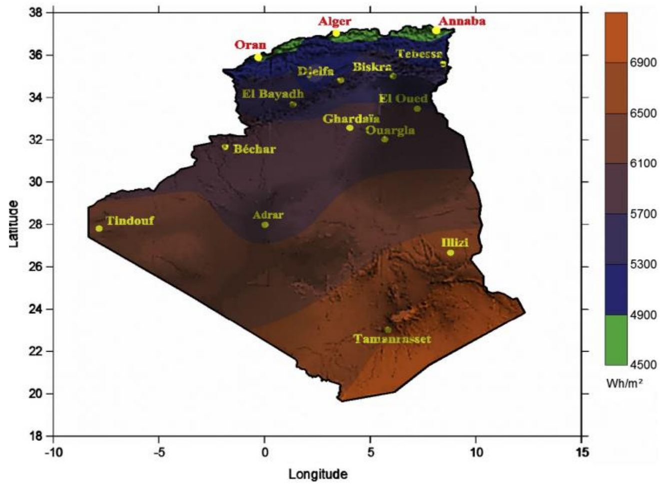


Figure 1. Average annual Global solar irradiation map of Algeria [25]

Figure 2. Radiometric station Solys2 at URAER in Ghardaia

In Algeria, the land and its distance and proximity to the sea affect the distribution of heat. Therefore, the temperature in the coastal strip is moderate in winter and summer, and the thermal range decreases. The measurement station on the Ghardaïa site in Algeria allows to measure and record meteorological data (Figure 2) such as temperature, humidity, pressure, wind speed and direction, as well as the three components of solar irradiation (global, diffuse and direct). Figures 3, 4 and 5 show the variation of the meteorological data (external stresses) concerning the average monthly global solar radiation, ambient temperature and relative humidity over a period from 2014-2017 (period including the date of the experiments). We can see that the global solar irradiation has the same tendency as the variation of ambient temperature.

It is observed that the average monthly radiation peak is recorded in July (7873 Wh/m^2) with a highest monthly ambient temperature around 35.4°C, corresponding to a minimum relative humidity of around 20.9%. The minimum monthly average radiation is 3053 Wh/m^2, while the minimum monthly temperature is 13°C, with a maximum relative humidity of 64.6% in December.

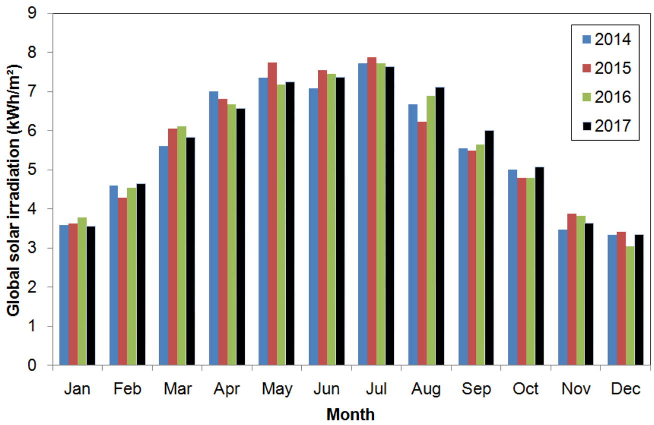


Figure 3. Monthly average of daily global solar irradiation in Ghardaïa (2014-2017)

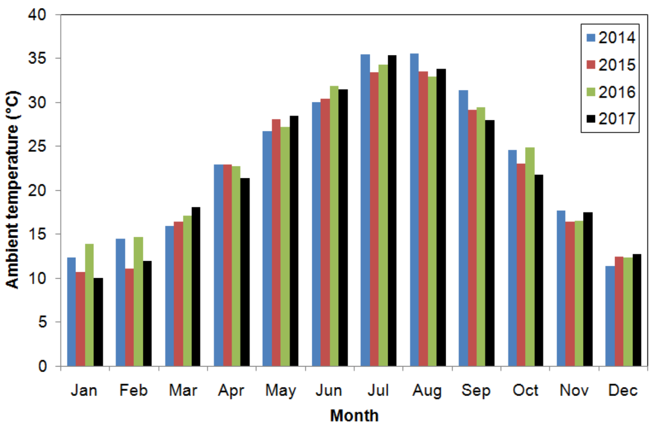


Figure 4. Monthly average of the ambient temperature in Ghardaïa (2014-2017)

Figures 3, 4 and 5 show the variation of the meteorological data (external stresses) concerning the average monthly global solar radiation, ambient temperature and relative humidity over a period the 2014-2017 (period including the date of the experiments). We can see that the global solar irradiation has the same tendency as the variation of the ambient temperature. It is observed that the average monthly radiation peak is recorded in July (7873 Wh/m^2) with a highest monthly ambient temperature around 35.4°C corresponds to a minimum relative humidity of around 20.9%. The minimum monthly average radiation is 3053 Wh/m^2 while the minimum monthly temperature is 13°C with a maximum relative humidity of 64.6% in December.

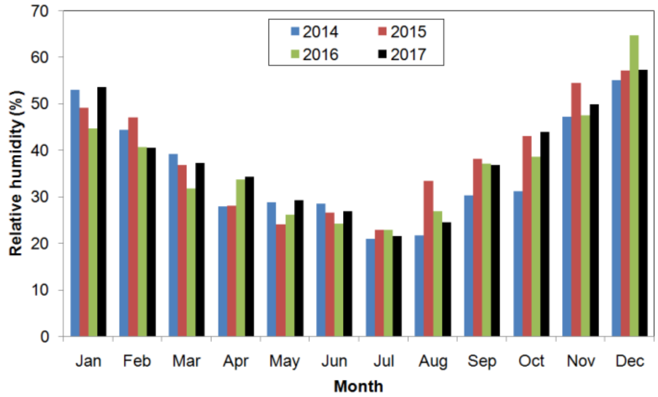


Figure 5. Monthly average of the relative humidity in Ghardaïa (2014-2017)

2.2 Greenhouse description

In this work, a tunnel agricultural greenhouse, commonly used in the Mediterranean region, it was designed and realized in southern Algeria. Exactly, in the Renewable Energy Applied Research Unit, UREAR in Ghardaïa.

Two tunnel type greenhouses with the same dimensions have been selected. However, one greenhouse was not equipped with a heating system which served as a witness (classic greenhouse), however, the other was equipped with a rock bed heating system named experimental greenhouse (Figure 6). In agreement to the finding of Aissa and Bezari [26], the orientation of both greenhouses is North-South with deviation to the west of about 20°, each greenhouse with 192 m^2 ground area (24m length by 8m width), with a heated volume around 442.6 m^3. The distance between the two greenhouses is seven times the height (for avoiding shadow). The wholly structure is stainless steel galvanized and fixed to the ground with stones and concrete.

The doors (2.15 m x 1.5 m) ensure optimal natural ventilation of the greenhouse. The greenhouses are covered with a simple skin LDPE (polyethylene with low density material of 180 μm of thickness). Its characteristics are given in Table 1.

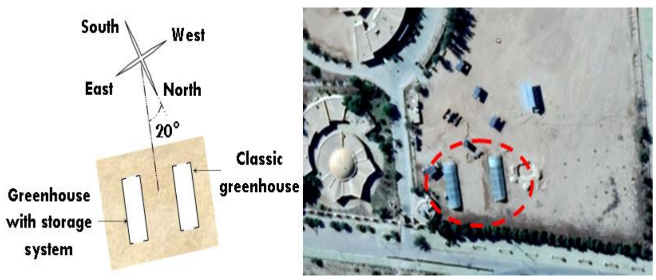


Figure 6. General view of the studied greenhouses in URAER, Orientation installation (left) and geographical position (right)

Table 1. The cover properties of the greenhouse

Properties	Values
Solar spectrum	
Absorptivity	0.2
Reflectivity	0.1
Transmittivity	0.7
Infrared spectrum	
Absorptivity	2.12
Reflectivity	0.07
Transmittivity	0.81

2.3 Heating system storage description

The rock-bed heating is a system based on sensible heat storage. The storage system in the tunnel greenhouse consists of four cylindrical PVC pipes, filled with nearly spherical gravels. The pipes are jointly forming two H-shape of 20 meter length. Each block has an inlet for the storage of thermal energy and four outputs for recovered thermal energy (Figure 7).

The spherical shape of the rocks used in this device thermal storage generates space between the rocks (porous medium) (Figure 8a), which facilitates the movement of air in the rock-bed, and then contributes to the very large surface exchange between rocks and air, which accelerates the heating process, leading to maximum storage of heat. Once the rocks were filled in the canals (see Figure 8b), they are buried at 800 mm deep in the greenhouse ground. The upper surface was then covered with soil to a sufficient depth. (Figure 8c).

According to the proposed heat storage system, in the daytime period, the excess heat available in the greenhouse is stored by transferring the hot air to the rock-bed (storage) through the heat transfer process by natural convection. But during cold nights the process reverses (destocking) so that the heat is taken from the rock layer and transferred to the indoor air by the phenomenon of natural convection. Heat is therefore released in different places of the greenhouse. The phenomena (storage/destocking) depend on the thermal state, height of the closed space and the movement of air inside the greenhouse. Ouarhlent et al. [27] provide this result about the heat and mass transfer induced by natural convection.

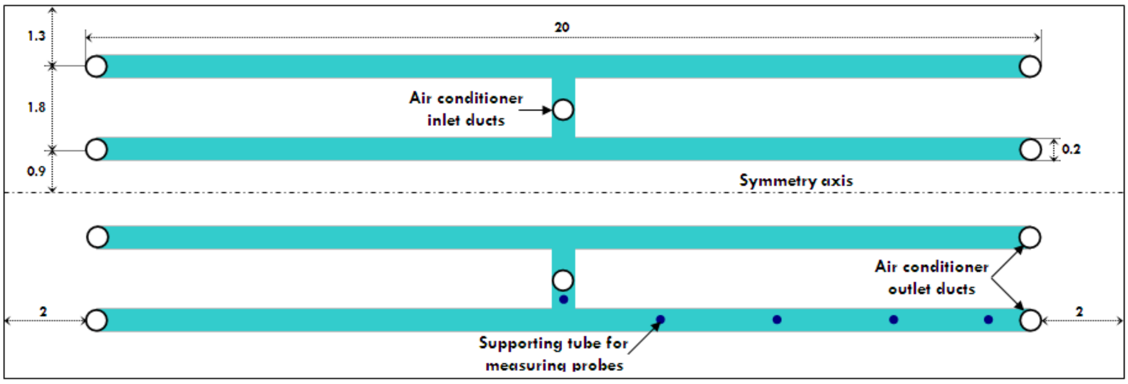


Figure 7. Rock-bed dimensions (m)

Figure 8. (a) and (b) Filling the pipelines with rocks, (c) Greenhouse structure and heating system, (e) Used rocks

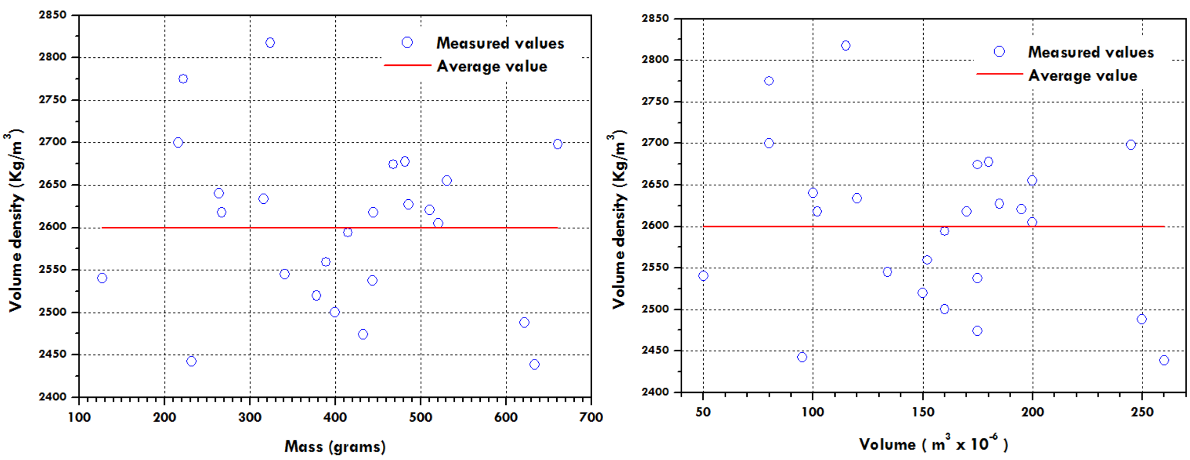


Figure 9. Measured values of the rock density

2.3.1 Rocks characteristics

Previously, the pipes were filled with rocks (washed and dried) with diameters ranging from of 50 to 100 mm (Figure 8e). Based on empirical measurements for the density calculation, a value ranging from 2439 to 2818 kg/m^3 has been reached according to Figure 9. It has a thermal conductivity of 5.1 W/m.K at 20°C with specific heat capacity of 652 J/Kg.k at 20°C. These indices ensure that the rocks have a high inertia, which will certainly ensure an intensive heat exchange with the surrounding medium.

In general, the spherical shape and its sizes are applied from 2-15 cm to serve the purpose.

They have a fast heat transfer, high energy storage capacity, high thermal conductivity, low cost and long cycle-life, abundance and impact on the environment [28, 29]. The characteristics of this rock-bed heating system are detailed in Table 2.

Table 2. The rock-bed characteristics

Volume of a single block	1.3 m^3
The mass of single block	9346 kg (measured)
Total volume of rock bed	2.6 m^3
Total mass of rock bed	18692 kg (measured)
Porosity	41% (measured)

2.4 Measurement instruments and uncertainty analysis

In the present study, the global radiation, temperature and relative humidity were measured by appropriate instruments explained below.

- The global solar radiation transmitted through the cover was measured by means of a pyranometer EPPLY.

- Measurements of temperature and relative humidity inside/outside the greenhouses were provided by two weather stations WS2-550.

A data logger (Agilent34970A) was used to monitor the measured values in real time within 10 minutes. Table 3 describes the sensors used in the heated greenhouse, in the classic greenhouse and outside greenhouses, as well as their names and accuracy.

It is important to calculate the error and uncertainty of all the measuring instruments used and the variables measured. For these uncertainties and errors are inevitable, due to the level of precision of the apparatus and the applied, either by notes or by reading [30, 31].

The calculation of the uncertainty of the measuring instruments and the variables measured were made using the Holman method [32] based on Eq. (1):

$$w_R = \left[\left(\frac{\partial R}{\partial V_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial V_2} w_2 \right)^2 + \cdots + \left(\frac{\partial R}{\partial V_n} w_n \right)^2 \right]^{1/2} \quad (1)$$

$R = R(V_1, V_2 \ldots V_n)$, is the error function versus n variables $(V_1, V_2 \ldots V_n)$, and $w_1, w_2 \ldots w_n$ represent the uncertainty range for each measured variable.

Table 3. Sensor accuracy and measuring range

Description	Sensors	Measurement range	Accuracy
Station radiometric Solys2	Pyranometer Kipp & zonen CMP11	0-4000 W/m^2 -40 to 80°C 0–100% RH	Expected daily accuracy < 2% Level accuracy 0.1°
Air temperature	PT-100	-50 to 200°C	+/ - 0.3°C
Data Acquisition	Data Logger Agilente 34970A	+/-100 mV +/-1V +/-10 mV +/-100 V +/-300 V	+/- (0.0050% of reading + 0.0040% of range), 18°C to 28°C +/- (0.0005% of reading + 0.0005% of range), 0°C to 18°C +/- (0.0005% of reading + 0.0005% of range), 28°C to 55°C
Weather station	LA CROSSE TECHNOLOGY WS2-550	T (outside): - 29.9°C to + 79.9°C T (inside): 0°C to + 60°C RH: 1-99% U: 0 to 200 km/h	+/- 0.8°C +/- 0.8°C +/- 5% Resolution: 0.1 km/h

3. RESULTS AND DISCUSSION

3.1 Hygro-thermal behavior of greenhouses: preliminary tests

Prior to testing the storage system, a comparison of the hygro-thermal behavior of the two greenhouses under the same environmental conditions (Ghardaïa site) was carried out. During this step, the air inlets and outlets were closed to avoid heat exchanges between the rock-bed and the greenhouse environment. This allows to suspend the sensible storage phenomenon and at the same time to avoid intensive conductive exchange between the rock-bed and the soil.

These experiments were conducted in two selected successive days, belonging to an off-season period (8-9 October, 2017). These days were cloudless; the measured horizontal solar irradiance exceeded the value of 820 W/m^2; wind speed was sometimes very low and tended to be zero at times; relative humidity was very low and had a random behavior ranging from 20% to 40%.

Figures 10 and 11 show the temperature and relative humidity results inside the two greenhouses, respectively. Under these circumstances, no crops were treated, the water content of the indoor air is very low and the soil is completely bare and uncovered. The selection was made on the basis of closed doors scenarios; infiltrations will not influence the evolution of the main measured parameters (indoor temperature and relative humidity).

The findings indicate that the temperature profiles are generally similar (Figure 10), while, the mean difference recorded is 0.45°C between the two cases. On the other hand, the mean value of the air temperature inside the classic greenhouse is 30.22°C, which corresponds to approximately 30.56°C for the greenhouse air supplied by the non-functional storage system. The maximum measured temperature values were fixed at 50.1 and 50.7°C, for the two greenhouses respectively.

Similarly, the minimum values exceed 16°C in both cases (16.10°C and 16.30°C) for the first and second greenhouse, respectively. The fluctuations are very important in both greenhouses, with the difference between the daily and night-time amplitudes exceeding a threshold of almost 34.2°C. In fact, it can be confirmed that the semi-arid climate gives rise to large amplitude in terms of outdoor temperatures, especially in the off-season, such as in April.

In addition, in the absence of a vegetation envelope that allows the heat to be absorbed, and by combining the previous climatic aspects with the greenhouse effect phenomenon that has appeared strongly in the area to be heated under strong light, they can have very important values both in terms of temperature and amplitude.

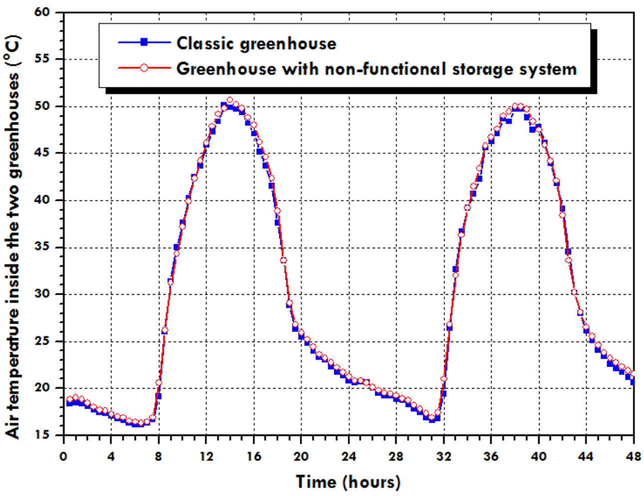


Figure 10. Temperature variation in the two studied greenhouses

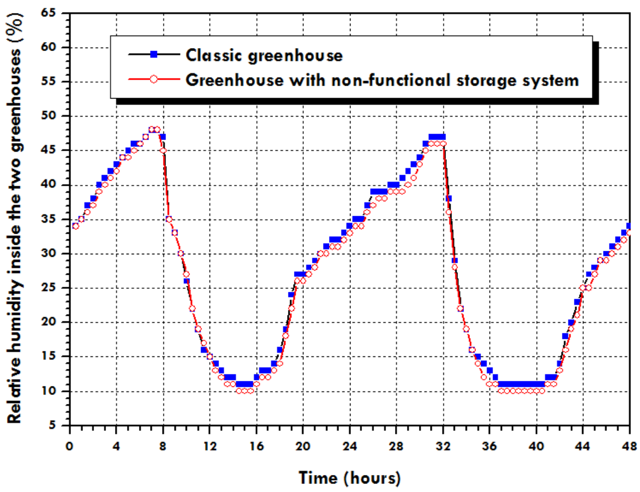


Figure 11. Relative humidity variation in the two studied greenhouses

Furthermore, the relative humidity curves also appear to be identical, but it can be noticed that this parameter is inversely proportional to temperature (Figure 11). The only interpretation that can be made is that the air water content can be almost fixed or generally stable. The linear regression curve (moisture versus temperature) indicates that the coefficient of determination R^2 is 0.92, whereas, the findings correspond well to the predictions shown in Figure 12. If this value is equal to 1, the air water content of the air will be absolutely fixed. If it is clearly variable, then a chaotic point cloud will result. Due to closed doors who did not promote sufficient incoming airflow to vary the air water content in air and, lack of evaporation transpiration for not having crops. Indoor climate has two aspects: generally dry, and sometimes very dry. The latter case indicates that the absolute and/or specific humidity value is reasonably low.

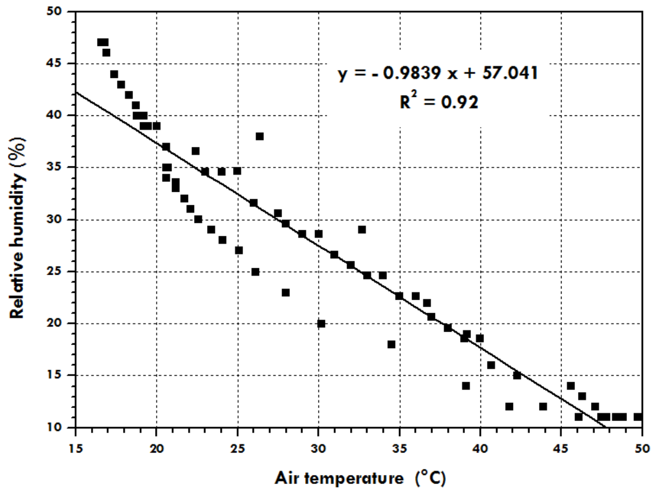


Figure 12. Temperature variation vs. relative humidity

The similarity of the curves obtained can be deduced by calculating the mean difference between the instantaneous values, which reaches 0.94. Consequently, the results obtained and the values retained strongly encourage comparative studies to be carried out on the new configuration of our storage system.

3.2 Integration of sensitive storage system

In the greenhouse, the main climatic factors such as solar radiation, air humidity, temperature and carbon dioxide greatly affect the growth and early maturity of greenhouse production from plants.

To carry out a judicious study on this new configuration of the passive heating system, cold days were selected, from December 01-03, 2017. They illustrate a clear sky; its days are calm and moderately humid. Figure 13 illustrates the variation of global, direct and diffuse solar radiation as a function of chosen days on a horizontal surface. It can be observed that the incident direct radiation increases from sunrise until it reaches its maximal level of 582 W/m^2 at noon. At this time of the day the sun is located at the zenith and transmitted energy is maximal regarding the fact that the cosine of the incidence angle is equal to unity. Then, the sun follows its trajectory and descends upon the horizon with sharp increase of incident angle yielding to very low solar radiations received at the ground. The direct beam thus decreases gradually until it reaches about zero value at 17h40 local time.

The Evolution of diffuse radiations is uniformly distributed around its average value of 92 W/m^2 representing 14% of global radiation. Whereas global solar irradiance records maximum values at 12:40 local time, where its average value is about 634 W/m^2.

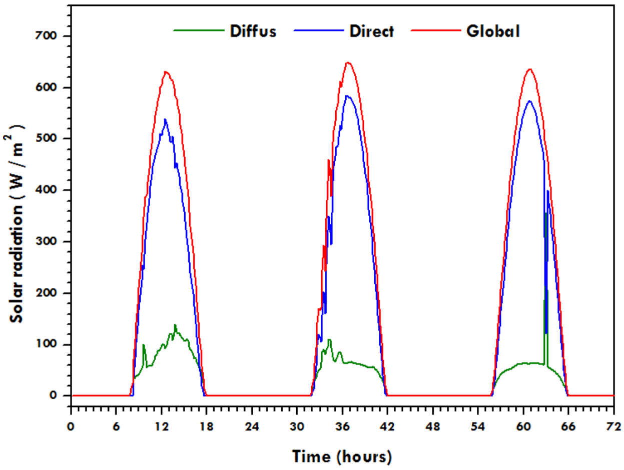


Figure 13. Variation of solar radiation

During this set of experiments, the soil remains nude and uncovered, the doors were closed. The difference compared to the previous study summarizes the fact that the aeration plugs have been removed, which will allow the natural convective exchanges in the rock-bed. As a result, the conductive exchanges between rocks and the soil can be neglected. The plotted curves in Figure 14, shows that the recorded temperatures (a 30 minutes increment) in the greenhouse have low values compared to the previous days, with maximums around 37.25°C. In this situation, the average observed values is in the order of 16.38°C. The minimum temperatures have crossed a record value, it's fixed at around 1.9°C.

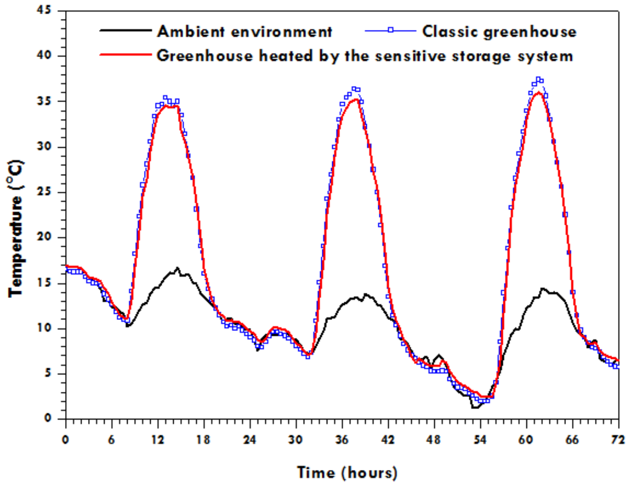


Figure 14. Temperature variations into the two greenhouses

Currently, during a clear sunshine day, the greenhouse effect will be created that increases the indoor temperature. The difference in temperature that appears between the air inside the greenhouse and the air in the rock-bed will create through the natural convection process a permanent flow that automatically generates a significant decrease of inside temperatures. This scenario justifies the main cause of the increase in temperatures in the control greenhouse. The maximum daily algebraic value of this difference is generally greater than 1.6°C. Regarding the relative humidity, the maximum daily algebraic difference is less than 2.5%. Regarding the nocturnal period, the found temperature in the experimental greenhouse was higher than that of the classic greenhouse with a value about 0.9°C and a decrease about 3.4% of relative humidity.

However, it can be noted again that in the absence of any source of latent heat and if a hygro-thermal zone is completely sealed, which the water content of the air is constant. Therefore the relative humidity variation (Figure 15) is both linear and inversely proportional to temperature. If this content is obviously variable, at that moment a random cloud of points can be obtained. To have more precision on the notable role of the water content, it is necessary to draw the linear regression function.

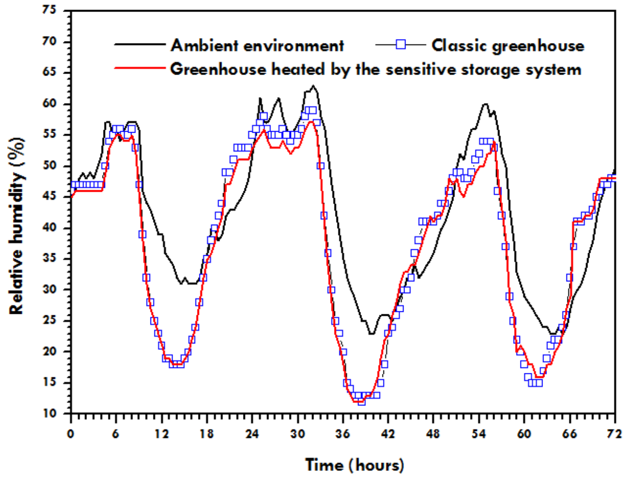
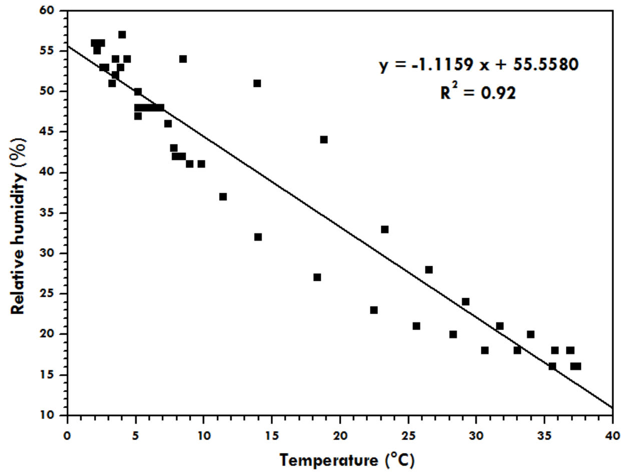


Figure 15. Relative humidity variations into the two greenhouses

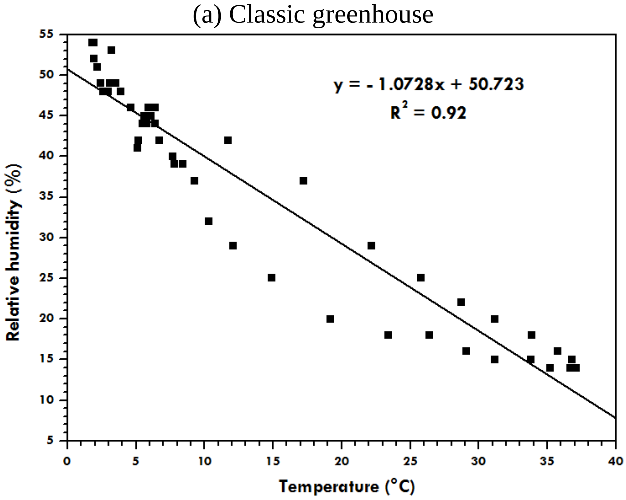
The graphs illustrate in Figure 16 (measured values and linear regression curves) that the straight spits are negative with a coefficient of determination R^2 estimated at 0.92. This value is nexus 1; the water content of the air is therefore often stable, which confirms that the relative humidity is generally inversely proportional to the temperature. That means that the convective flow of incoming air is low because of the closed doors, even seepage will not significantly affect the evolution of indoor climate factors. Consequently, the airflow rate is the first responsible for the variation of the water content of the air. Moreover, the indoor climate of both greenhouses will become very dry for sufficiently high temperatures. The results showed again prove that the hydrothermal behavior is generally identical. The average difference between the instantaneous values in temperature and relative humidity is 0.45°C and 3.5% respectively.

Generally, during the convection process, the increase of the air velocity (natural or forced) favors the possibilities of transformation of a laminar flow into a turbulent one, thus generating a turbulent convection which considerably accelerates the exchanges of properties between layers close to the air and in particular the diffusion of heat within it. Thus the energy is transferred due to diffusion; it can also be transferred by the movement of the fluid (free or natural movement). The latter is associated with the fact that multiple molecules have a collective motion, which implies a heat transfer in the case where there is a thermal gradient.

Following the previous observation, it can be deduced that natural convection is not enough to obtain a good heat exchange between the air inside the greenhouse and stone pebbles. The temperature gradient in this case is not sufficient and therefore does not induce movement in the air. These results allow us to think in a way of active solar heating in order to ensure a better distribution of heat and to conserve a better quantity of energy.



(a) Classic greenhouse



(b) Experimental greenhouse

Figure 16. Variation of temperatures as a function of relative humidity

4. CONCLUSIONS

In this paper, an experimental study of a newly designed heat storage system, with an H-shape channel rock-bed integrated into a greenhouse. The excess heat was stored in the rock-bed and restored during the night period. This stored energy is extracted from the greenhouse by natural convection and radiant heat. The findings of this study have revealed a good efficiency of the solar greenhouse heating system by improving its local climate. The temperature during the day is reduced by 1.6°C. Furthermore, the temperature of the greenhouse inner air is increased by 0.9°C during the night and the air relative humidity is decreased by 3.4%. This improvement in the greenhouse climate environment during the cold winter nights can positively effect plant development and crops quality. The rock-bed storage system is environmentally friendly; moreover, it is durable design for agricultural use in various sites and types of greenhouses.

In order to improve the heat storage system efficiency it is necessary to optimize most of the geometry and thermal parameters such as (dimensions and shape of the system, flow velocities, storage materials, etc.). This requires future works such as:

- Determine the equivalent diameter and length of the bed, to have good heat exchange between the air and the rocks.
- Integration of an active heating system (controlled ventilation, pump)
- Use another material such as phase change materials (PCM) for energy storage system.
- Modeling the solar greenhouse thermal aspect using the intelligent learning (ANN, Bond graphic...) method to control the greenhouse microclimate and improvement the performance of the storage system.

ACKNOWLEDGMENT

This study was supported by Direction General for Scientific Research and Technological Development (DG-RSDT) in Algeria. We thank A. Bouhdjar for valuable discussions and W. Radouane & A. Ouanes for technical assistance.

REFERENCES

[1] Mesmoudi, K., Meguellati, K., Bournet, P.E. (2017). Thermal analysis of greenhouses installed under semi arid climate. International Journal of Heat and Technology, 35(3): 474-486. https://doi.org/10.18280/ijht.350304

[2] Bouadila, S., Lazaar, M., Skouri, S., Kooli, S., Farhat, A. (2014). Assessment of the greenhouse climate with a new packed-bed solar air heater at night, in Tunisia. Renewable and Sustainable Energy Reviews, 35: 31-41. https://doi.org/10.1016/j.rser.2014.03.051

[3] Bezari, S., Bouhdjar, A., Ait-Messaoudenne, N. (2007). Etude du microclimat d'une serre tunnel équipée d'un dispositif de stockage thermique dans l'eau. In International Congress on Renewable Energy and Sustainable Development, Tlemcen. pp. 307-113. https://www.cder.dz/download/ICRESD07_44.pdf.

[4] Sethi, V.P., Sharma, S.K. (2008). Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications. Solar Energy, 82(9): 832-859. https://doi.org/10.1016/j.solener.2008.02.010

[5] Esen, M., Yuksel, T. (2013). Experimental evaluation of using various renewable energy sources for heating a greenhouse. Energy and Buildings, 65: 340-351. https://doi.org/10.1016/j.enbuild.2013.06.018

[6] Singh, P.L., Deshpandey, S.D., Jena, P.C. (2015). Thermal performance of packed bed heat storage system for solar air heaters. Energy for sustainable Development, 29: 112-117. https://doi.org/10.1016/j.esd.2015.10.010

[7] Ayyappan, S., Mayilsamy, K., Sreenarayanan, V.V. (2016). Performance improvement studies in a solar greenhouse drier using sensible heat storage materials. Heat and Mass Transfer, 52(3): 459-467. https://doi.org/10.1007/s00231-015-1568-5

[8] Kürklü, A., Bilgin, S., Özkan, B. (2003). A study on the solar energy storing rock-bed to heat a polyethylene tunnel type greenhouse. Renewable Energy, 28(5): 683-697. https://doi.org/10.1016/S0960-1481(02)00109-X

[9] Bazgaou, A., Fatnassi, H., Bouhroud, R., Gourdo, L., Ezzaeri, K., Tiskatine, R., Demrati, H., Wifaya, A., Bekkaoui, A., Aharoune, A., Bouirden, L. (2018). An

experimental study on the effect of a rock-bed heating system on the microclimate and the crop development under Canarian greenhouse. Solar Energy, 176: 42-50. https://doi.org/10.1016/j.solener.2018.10.027

[10] Gourdo, L., Bazgaou, A., Ezzaeri, K., Tiskatine, R., Wifaya, A., Demrati, H., Aharoune, A., Bouirden, L. (2018). Heating of an agricultural greenhouse by a reservoir filled with rocks. Journal of Materials and Environmental Sciences, 9(4): 1193-1199. https://doi.org/10.26872/jmes.2017.9.4.131

[11] Gourdo, L., Fatnassi, H., Bouharroud, R., Ezzaeri, K., Bazgaou, A., Wifaya, A., Demrati, H., Bekkaoui, A., Aharoune, A., Poncet, C., Bouirden, L. (2019). Heating canarian greenhouse with a passive solar water–sleeve system: Effect on microclimate and tomato crop yield. Solar Energy, 188: 1349-1359. https://doi.org/10.1016/j.solener.2019.07.004

[12] Hassanien, R.H.E., Li, M., Tang, Y. (2018). The evacuated tube solar collector assisted heat pump for heating greenhouses. Energy and Buildings, 169: 305-318. https://doi.org/10.1016/j.enbuild.2018.03.072

[13] Ghosal, M.K., Tiwari, G.N. (2006). Modeling and parametric studies for thermal performance of an earth to air heat exchanger integrated with a greenhouse. Energy Conversion and Management, 47(13-14): 1779-1798. https://doi.org/10.1016/j.enconman.2005.10.001

[14] Lazaar, M., Bouadila, S., Kooli, S., Farhat, A. (2015). Comparative study of conventional and solar heating systems under tunnel Tunisian greenhouses: Thermal performance and economic analysis. Solar Energy, 120: 620-635. https://doi.org/10.1016/j.solener.2015.08.014

[15] Bargach, M.N., Dahman, A.S., Boukallouch, M. (1999). A heating system using flat plate collectors to improve the inside greenhouse microclimate in Morocco. Renewable Energy, 18(3): 367-381. https://doi.org/10.1016/s0960-1481(98)00803-9

[16] Baddadi, S., Bouadila, S., Ghorbel, W., Guizani, A. (2019). Autonomous greenhouse microclimate through hydroponic design and refurbished thermal energy by phase change material. Journal of Cleaner Production, 211: 360-379. https://doi.org/10.1016/j.jclepro.2018.11.192

[17] Chen, C., Ling, H., Zhai, Z.J., Li, Y., Yang, F., Han, F., Wei, S. (2018). Thermal performance of an active-passive ventilation wall with phase change material in solar greenhouses. Applied Energy, 216: 602-612. https://doi.org/10.1016/j.apenergy.2018.02.130

[18] Öztürk, H.H. (2005). Experimental evaluation of energy and exergy efficiency of a seasonal latent heat storage system for greenhouse heating. Energy Conversion and Management, 46(9-10): 1523-1542. https://doi.org/10.1016/j.enconman.2004.07.001

[19] Kooli, S., Bouadila, S., Lazaar, M., Farhat, A. (2015). The effect of nocturnal shutter on insulated greenhouse using a solar air heater with latent storage energy. Solar Energy, 115: 217-228. https://doi.org/10.1016/j.solener.2015.02.041

[20] Xu, J., Wang, R.Z., Li, Y. (2014). A review of available technologies for seasonal thermal energy storage. Solar Energy, 103: 610-638. https://doi.org/10.1016/j.solener.2013.06.006

[21] Zhao, D.L., Li, Y., Dai, Y.J., Wang, R.Z. (2011). Optimal study of a solar air heating system with pebble bed energy storage. Energy Conversion and Management, 52(6): 2392-2400. https://doi.org/10.1016/j.enconman.2010.12.041

[22] Solargis, Solar resource maps of Africa, Global horizontal irradiation. https://solargis.com/maps-and-gis-data/download/Africa, accessed on June 16, 2020.

[23] Amara, S. (2011). Novel and ancient technologies for heating and cooling buildings. Ph.D. dissertation. Luleå University of Technology (LTU). SE-97187 Luleå, Sweden.

[24] Benkaciali, S., Haddadi, M., Khellaf, A. (2018). Evaluation of direct solar irradiance from 18 broadband parametric models: Case of Algeria. Renewable Energy, 125: 694-711. https://doi.org/10.1016/j.renene.2018.02.108

[25] Yaiche, M.R., Bouhanik, A., Bekkouche, S.M.A., Malek, A., Benouaz, T. (2014). Revised solar maps of Algeria based on sunshine duration. Energy Conversion and Management, 82: 114-123. https://doi.org/10.1016/j.enconman.2014.02.063

[26] Aissa, M., Bezari, S. (2018). The orientation effect of the agricultural tunnel greenhouse on aerodynamic and energy properties. 2018 5th International Symposium on Environment-Friendly Energies and Applications (EFEA), Rome, Italy. https://doi.org/10.1109/EFEA.2018.8617097

[27] Ouarhlent, F., Soudani, A. (2019). Numerical study of thermal convection in a porous medium. Instrumentation Mesure Métrologie, 18(1): 69-74. https://doi.org/10.18280/i2m.180111

[28] Benchatti, T., Medjelled, A., Benchatti, A. (2013). Enhancement of the efficiency of an underground thermal energy storage system (Laghouat, Algeria). International Journal of Heat and Technology, 31(1): 135-142. https://doi.org/10.18280/ijht.31011

[29] R. Tiskatine, R., Eddemani, A., Gourdo, L., Abnay, B., Ihlal, A., Aharoune, A., Bouirden, L. (2016). Experimental evaluation of thermo-mechanical performances of candidate rocks for use in high temperature thermal storage. Applied Energy, 171: 243-255. https://doi.org/10.1016/j.apenergy.2016.03.061

[30] Kirkup, L., Frenkel, R.B. (2006). An Introduction to Uncertainty in Measurement: Using the GUM (Guide to the Expression of Uncertainty in Measurement). Cambridge University Press.

[31] Coleman, H.W., Steele, W.G. (2018). Experimentation, Validation, and Uncertainty Analysis for Engineers. John Wiley & Sons.

[32] Holman, J.P. (2006) Experimental Methods for Engineers. McGraw-Hill.