# Investigation and Improvement for a Solar Greenhouse Using Sensible Heat Storage Material


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*Greenhouses need energy to create a suitable climate for crop production in winter period. Renewable energy seems to be the appropriate and sustainable energy source to heat greenhouses. The aim of this work is to investigate the possibilities of improving the inner greenhouse climate using sensible heat storage material. A comparative study was conducted upon experimental tests carried out between control and heated greenhouse in a semi-arid region. A new design of greenhouse was proposed that consists of an economical rock-bed with the sensible heat technique for heating system in an integrated H-shape channel. The excess diurnal heat captured by the greenhouse is stored into the system and then restored for nocturnal heating. The results obtained indicate that this thermal storage system is efficient and ameliorates the greenhouse climate. The night temperature was improved by 3.2 °C and the relative humidity was reduced by 9.6%, compared to a standard greenhouse.*



***Keywords:*** *Solar energy, Heat storage, Greenhouse, Heating system control, Measurements.*


## 1. INTRODUCTION

A greenhouse is originally designed as a simple incubator limited by a transparent cover, which stores long-wavelength thermal radiation as well as short wavelength solar radiation. Moreover, it provides an adequate and adaptable climatic environment to achieve a high yield in terms of product quantity and quality. Agricultural production requires continuous monitoring of the local greenhouse climate.

The main function of a greenhouse is to optimise the climate and growth factors and parameters such as humidity, light, temperature and nutrients, in a way to create a suitable climate for various crops and maintained at optimal levels [1, 2]. Many researchers have studied the influence of greenhouse shape, construction and orientation [3] under various cover materials and different types of greenhouses [4].

During the cold season (winter), extreme climatic conditions can lead to a drop in temperature and a sharp increase in humidity inside the greenhouse. This occurs especially during the night period and causes the development of diseases and slows down plant development, which also affects yield and product quality. Therefore, the use of an appropriate heating system becomes necessary to improve internal climatic factors and optimal agricultural production during the winter.

Currently, conventional units are used to heat the greenhouse, including boilers and fossil fuels [5]. Today, the cost of fossil fuels is increasing significantly [6], leading to higher production costs and lower income for farmers. The use of renewable energies for heating greenhouses can be an alternative that meets the demand for low-cost energy in an environmentally friendly way. Therefore, much work has focused on the orientation towards renewable and new energy sources worldwide [7].

Greenhouse heating is the most widely used renewable energy source in agriculture, mainly geothermal [8], solar [9] and biomass [10]. In greenhouses, heating systems based on solar thermal energy are often used. Solar thermal energy is stored as sensible heat, latent heat or a combination of both. Several works have been proposed in the literature describing greenhouse heating systems that use sensible heat storage such as water storage [11], rock-bed storage [12], ground storage [13], aquifer storage [14] and solar collectors [15].

Phase change materials CaCl2 6H2O, Na2SO4 10H2O and paraffin are considered latent heat storage materials, although they are used in many applications such as greenhouse heating [16]. Based on current price indices, the use of CaCl2 6H2O costs about five times more than employing a rock device with similar amount of thermal energy. However, the water storage system requires a very large amount of thermal energy storage material [17] and pumping costs. While sensible thermal storage is an advanced technology that has shown great promise in recent times due to its many operational advantages. The rock collect system is itself a heat exchanger without requiring any heat exchanger surface. It is easy to use and practical, which reduces the overall cost and increases profitability [18]. The sensible heat storage materials are less expensive and have greater thermal conductivity than phase change materials [19].

Most of these systems are very expensive or difficult to implement. Related studies to this issue focus more on the effect of the heating system on the prevailing climate in the greenhouse, without paying much attention to the agricultural standards, such as plant growth and agricultural yields.


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Through the current study, a novel design has been proposed to set an economical and practical rock bed heating system in tunnel greenhouse installed in the region of Ghardaïa, Algeria. Under the local semi-arid climatic characteristics of the site, the temperature during the nocturnal period is very low compared to the daytime period in winter season. In order to overcome this problem, the excess heat collected during the day was stored in the system, and then used at night for heating upon the need of greenhouse. Emphasis will be placed on the impact that the resulting heating system will have on local climate, plant growth, and agricultural yield under the tunnel greenhouse.

## 2. INVESTIGATED SITE CHARACTERISTICS

Ghardaïa site is located between (32.36° North, 3.51° West and 450 m above sea level). The region has a semi-arid climate (cold winter and hot summer) characterized by exceptional sunshine, with a very high solar radiation rate (75% in average) and a mean annual global solar radiation received over a horizontal surface that exceeds 20 MJ/m². The mean sunshine duration is more than 3000 hours per year, which is favorable for the implementation of different solar projects [20].

The two typical sunshine duration values (lowest and highest) were recorded in December (234.5 hours) and July (337.3 hours), respectively. The mean sunshine duration recorded during the decade 2000-2009 is about 3391.20 hours per year (9 hours/day). The mean annual temperature is about 22.61 °C, with the minimum and maximum averages recorded in January (the coldest month) being about 5.5 °C and the maximum average in July (the hottest month) being about 41.7 °C, respectively. Relative humidity is very low, around 21.60% in July, but reaches a maximum of 55.80% in January and a mean annual of 38.33% [21].

The temperature currently varies in a considerable range between daytime and night-time values with a value of about 16 °C, while the perceived humidity level in the Ghardaïa region does not change much during the year. The hourly average wind speed in the region shows a moderate seasonal variation throughout the year. The windiest period of the year is recorded during 6 months and nine days, from early January and to mid-July, when the average wind speed exceeds 4.1 m/s. The windiest day of the year is April 27, when the average wind speed is 4.6 m/s.

The calmest period of the year generally lasts five months and twenty-one days, from mid-July to early January. The calmest day of the year is usually the last half of October, with an average hourly wind speed of 3.6 m/s. Consequently, the above-mentioned analysis of the collected value should illustrated the typical solar potential and local meteorological characteristics of the Ghardaïa area, based on the statistical analysis of historical hourly weather reports and models studied between January 1, 1980 and December 31, 2016 [22].

Table 1 shows the long-term average values representing the climatic conditions of the Ghardaïa site, including: monthly average values of relative humidity, solar radiation, wind speed, and minimum, maximum and average outdoor temperatures. During the heating period from November to April, the energy demand for heating increases in January while it decreases since the beginning of April.

## 3. SYSTEM DESCRIPTION

The experiments were conducted in tunnel greenhouses with metal structures, an estimated heated volume of approximately 442.6 m$^3$ and a surface area of 24 m long by 8 m wide. The research work was carried out in the Renewable Energy Applied Research Unit (UREAR), in Ghardaïa, Algeria.

### 3.1 Description of the experimental greenhouse

Two tunnel type greenhouses with the same dimensions were selected. The classic greenhouse was not equipped with a heating system served in a conventional way, while the experimental greenhouse was equipped with a rock-bed heating system (Figure 1). Both greenhouses were oriented north-south with a deviation angle of about 20°, towards the west, implanted on a ground area of about 192 m² each. The distance between the two greenhouses was seven times the height. The green-houses were covered with a single-skin LDPE (low-density polyethylene), with 180 μm thick, 0.73 transmissivity and 0.2991· 10$^{-6}$ m²/s diffusivity.

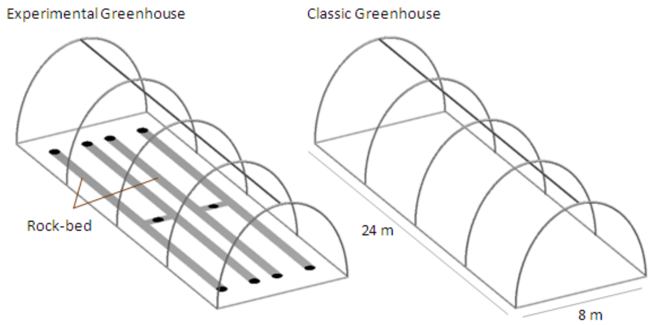



**Figure 1. Schematic view of the studied greenhouses**

### 3.2 Description of the heating system storage

Sensible heat storage is considered to be the basis of the rock-bed heating system, which is often used according to certain technical and economic possibilities. The storage system in the tunnel greenhouse consists of four parallel PVC tubes (200 mm in cross-section), each of the two tubes being joined together adjacently (block) forming the H-shape, filled with spherical rock varying from 50 to 100 mm in diameter (Figure 2). Based on these indexes and characteristics, it was found that rocks could be used as a means of thermal storage. They are often used in the Ghardaïa region because of their ease of use, availability, low cost and insensitivity to cor-rosion. They are also chemically inactive due to air contact. Table 2 illustrates the characteristics of the rocks used in our tests.

Each block has one inlet for thermal energy storage and four outputs for recovered thermal energy as illustrated in Figure 3. The upper surface was then covered with soil to a depth sufficient to allow root development and promote plant growth.

**Table 1. Ghardaïa's climatic conditions during the 2017-2018 heating season**

| | Months | | | | | |
|---|---|---|---|---|---|---|
| | November | December | January | February | March | April |
| Average outdoor temperature (°C) | 15.5 | 11.1 | 12.1 | 12.2 | 18.1 | 20.94 |
| Minimum outdoor temperature (°C) | 6.3 | 1.3 | 3.7 | 2.6 | 4.6 | 9.8 |
| Maximum outdoor temperature (°C) | 29.6 | 23.6 | 24.2 | 23.8 | 31.2 | 35.4 |
| Average relative humidity (%) | 43.2 | 49.1 | 46.7 | 47.3 | 36.1 | 36.7 |
| Average wind velocity (m/s) | 2.9 | 2.3 | 2.8 | 1.7 | 2.2 | 2.1 |
| Average solar radiation (W/m²) | 166.8 | 140.6 | 148.1 | 180.5 | 230.1 | 267.2 |

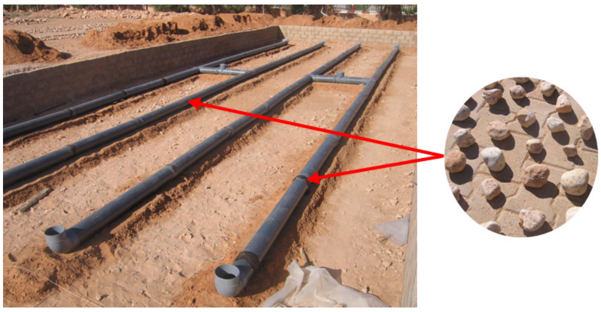


**Figure 2. PVC tubes in H-shape filled with rocks**

**Table 2. Characteristics of the rocks**

| Characteristics | Values |
|---|---|
| Equivalent diameter | 5 to 10 cm |
| Average density | 2600 kg/m$^3$ |
| Thermal conductivity | 5.1 W/m.k |
| Specific heat at20 °C | 652 J/Kg.k |

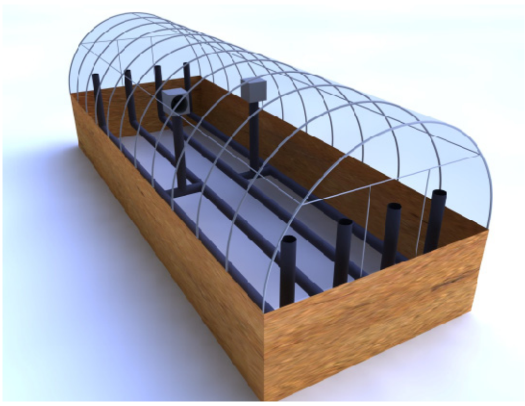


**Figure 3. A rock-bed heating system in a greenhouse**

The selection of the pipe material was made taking into account the expansion and shrinkage of the pipe (20 cm in diameter and 6 mm thick) due to its characteristics and influenced by the change in temperature. As a result, the coefficient of expansion of the PVC plastic materials was about 0.06 mm/m/°C, the conductivity of the pipe was about 0.17 Wm-1K-1while its density was 1400 kg/m3. Table 3 summarizes the physical properties of the rock-bed.

**Table 3. The rock-bed characteristics**

| Characteristics | Values |
|---|---|
| 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) |

Two fans were placed in the middle of the storage device. Each block inlet was equipped with a fan for storage and destocking operations (Figure 4a). Each fan had a 220 mm head, an air flow rate of 19.5 m$^3$/min and a power consumption of 55 W, which were used to push the air through the rocks. The fans were then connected to an intelligent temperature control system (thermostats) to ensure that the entire system operated properly (day and night) (Figure 4b).

Table 4 describes the sensors used in the heated greenhouse, in the classic greenhouse and outside greenhouses, as well as their names and accuracy.

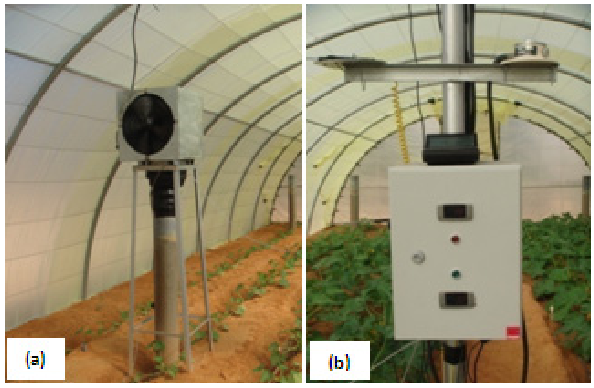



**Figure 4. (a) Fan; (b) Smart temperature control system**

**Table 4. Characteristics of the sensors used in this experiment**

| Description | Sensors | Unity | Accuracy |
|---|---|---|---|
| Global solar radiation | Pyranometer Eppley | W/m² | ±0.2° |
| Station radiometric Solys2 | Pyranometer Kipp&Zonen CMP11 | W/m² | ±0.1° |
| Platinum probes | PT-100 | °C | ±0.3°C |
| Weather station | La Crosse Technology ws2-550 | °C | ± 0.8°C |
| | | % | ± 0.8°C |
| | | m/s | ±5% |

When storing or destocking heat, the air in the greenhouse is pushed by a fan through the rock-bed and controlled by two thermostats.

Figure 5 illustrates the rock-bed system operating principles. During daytime, the circulation of warm air through the rock-bed allows the storage of excess heat available in the greenhouse (starting at a thermostat temperature of 28 °C). At the same time, the cold air stored overnight is released, which helps to cool the greenhouse air throughout the day.

During the night period (from 11.30 p.m. to 7.00 a.m.), while the cold air in the greenhouse is injected in to the rock-bed, the process is reversed (destocking phase): the heat emitted by the rock-bed is dispatched inside the air greenhouse via the fans (from a thermostat temperature of 14 °C).

### 3.3 Thermal load leveling

Fluctuating indoor air temperature in the greenhouse has a significant influence on plant development and health. These temperature quantities are quantified by a relative factor called thermal load leveling (TLL). This is an important factor for the optimization of the greenhouse heating parameters. In addition, a better environment for plants is ensured when the indoor temperature has minimal fluctuations, so that the TLL will have a minimum value [23].

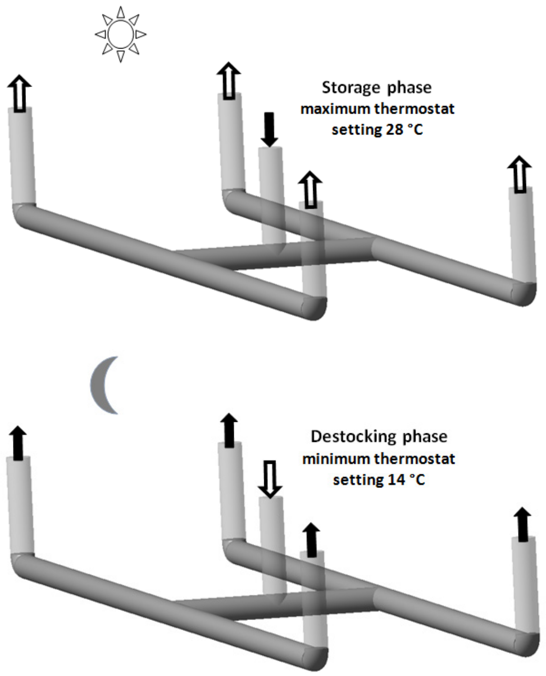



**Figure 5. Operating principles of the rock-bed heating system**

The performance of the thermal storage system in the heated greenhouse relative to the control system, for greenhouse applications, was evaluated in terms of TLL, using the following equation [24]:

$$TLL = \frac{(T_{indoor,max} - T_{indoor,min})}{(T_{indoor,max} + T_{indoor,min})} \quad (1)$$

TLL gives an idea of the temperature fluctuation inside the greenhouse. A better environment for the plants inside the greenhouse is ensured by less temperature fluctuation.

## 4. RESULTS AND DISCUSSION

The main climatic parameters in the greenhouse are solar radiation, air humidity, temperature and carbon dioxide. They have a significant influence on the growth and early maturity of greenhouse production of zucchini. To show the effect of heating clearly, three days during heating season were chosen namely: 29, 30 and 31 January 2018.

Figure 6 illustrates the daily behavior of solar radiation components in the outdoor greenhouse during experimental days. The global solar radiation received on horizontal surface varies from 673 to 736 W/m², while for the diffuse component it is strong when the day is partially cloudy or overcast. For the direct solar radiation, it is also strong when the sky is clear.

Figure 7 shows the daily variations of the environmental temperature and the air temperature inside the experimental and the classic greenhouses (for the same 3-day period). It can be observed that the recorded outdoor temperature is lower than the one recorded inside both greenhouses. This is caused by the greenhouse effect through the diurnal period, when the maximum daily temperature reached in the environment was about 16 °C. Hence, a significant decrease was noticed during the night (up to 5 °C).

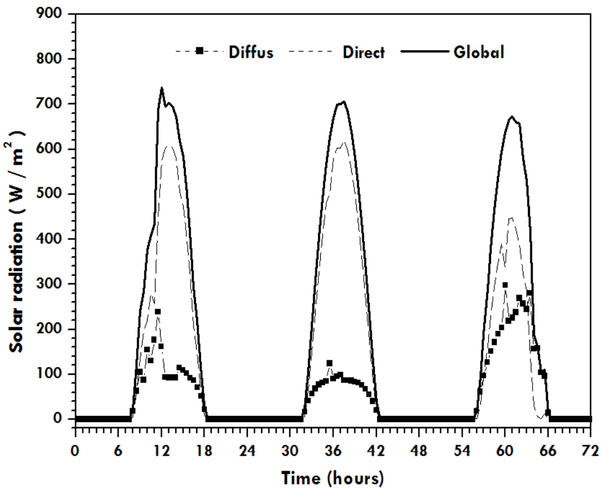



**Figure 6. Evolution of solar radiation outside the greenhouse**

It is important to remember that the energy storage system only starts to operate at the internal temperature of the greenhouse, i.e. about 28 °C. However, it starts to operate again when the temperature is below 14 °C (vegetative zero) for a timely (overnight) recovery heating. In addition, it can be observed that in the classic greenhouse the air temperature increases gradually by 11 °C in the morning, up to a maximum value of 39 °C at 1 p.m., whereas it increases gradually by 11 °C up to a maximum value of about 34 °C during the same period in the experimental greenhouse. This is a significant difference that can be reached at a value of 5 °C, due to the effect of the heat storage process that takes place in the experimental greenhouse.

With regard to the night period, the temperatures obtained revealed that the values recorded in the experimental greenhouse are higher than those recorded in the classic greenhouse, which can reach a level of about 3.2 °C. The increase in temperature is due to the recovery of heat stored in the rock-bed during the day. This also shows that the storage device contributes effectively to the greenhouse climate.

Figure 8 shows that the difference in indoor air temperature between the greenhouses is significant. The average night-time difference recorded during the period (6.30 p.m. - 7.30 a.m.), between the indoor air temperature of the experimental and classic greenhouses is 2.5 °C with a maximum of 2.8 °C. This means an improvement of the climatic conditions in the greenhouse as a result of the activation of the thermal storage system.

During the day, the system maintains a temperature above the optimal temperature for the best growth of the crop (25 °C). The storage system raised the nighttime indoor temperature to a maximum of 3.2 °C compared to the classic greenhouse. With the exception of the early morning hours, recorded from 4 to 6 a.m., this is a period during which the climatic environment outside the greenhouse is extremely cold.

Figure 9 presents the variation of the relative humidity in the ambient environment, as well as inside the two greenhouses (experimental and classic). It can be noticed that the relative humidity of the outside environment varies between 35% and 71% during the daytime and nighttime, respectively. In addition, the humidity during the night is higher compared to the day, which was noted for the two greenhouses.

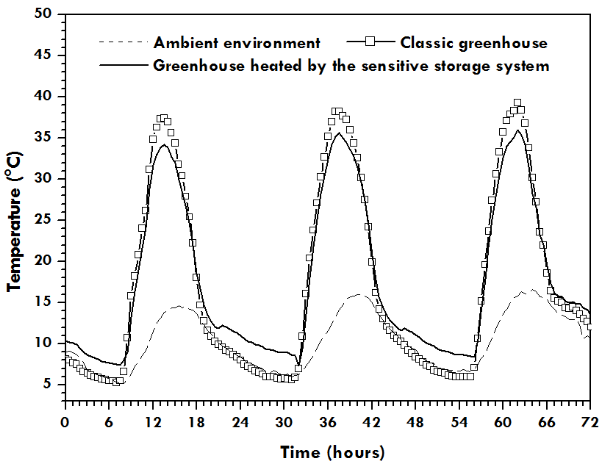



**Figure 7. Air temperature variation with time of outside/inside greenhouse with and without heating**

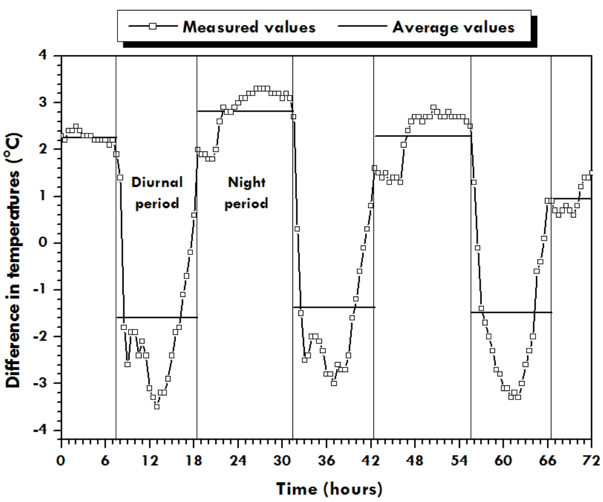



**Figure 8. Air temperature gaps inside both experimental and classic greenhouse**

However, the relative humidity in the classic greenhouse is relatively high at night and decreases during the day. The relative humidity of the indoor air during the day is lower than that of the outdoor air. This difference can be as much as 11% at 2 p.m. local time, due to the greenhouse effect that occurs in the greenhouse, making it drier. On the other hand, during the night, the relative humidity in greenhouses is higher compared to the ambient environment.

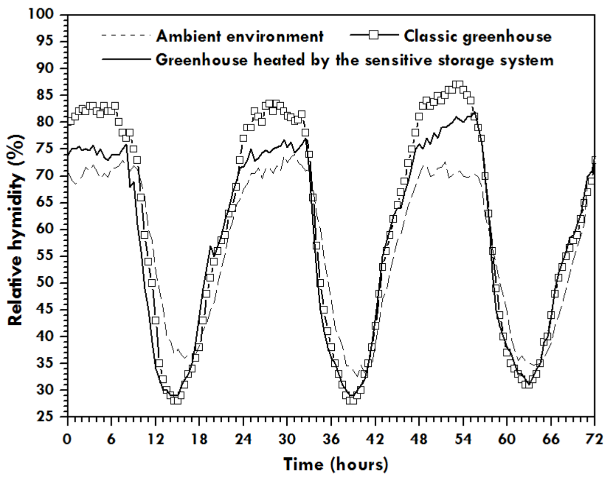



**Figure 9. Relative humidity variation inside the classic greenhouse, the experimental greenhouse and the outdoor environment**

Due to the presence of plantings in the greenhouse as well as the contact of the air with the water-saturated soil, high relative humidity is caused by the phenomenon of evaporation. Therefore, it is indicated that the presence of a thermal storage device (rock-bed) reduced the relative humidity compared to the classic greenhouse.

The results presented in Figure 10 indicate that the differences in relative humidity for the two greenhouses are due to the prevailing climatic conditions. Indeed, throughout the day, the relative humidity of the indoor air in the heated greenhouse is higher than that recorded in the classic greenhouse, where the difference can be as high as 2%, which is proved by the phenomenon of storage in the rock-bed. The result is a drop in temperature when the destocking phenomenon reduces the night-time relative humidity in the experimental greenhouse, which, when significantly reduced, can reach the value of about 9.6%.

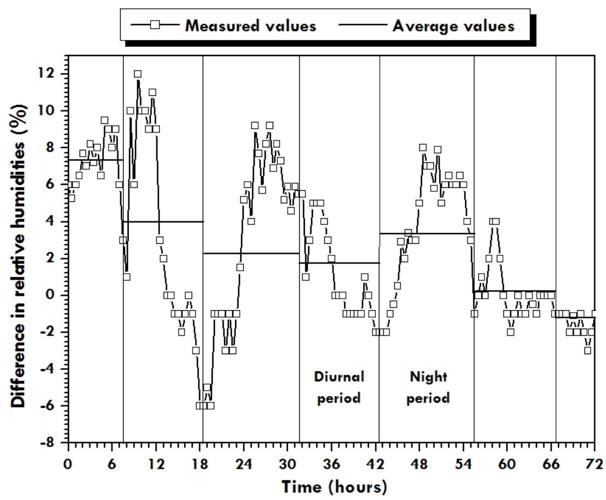
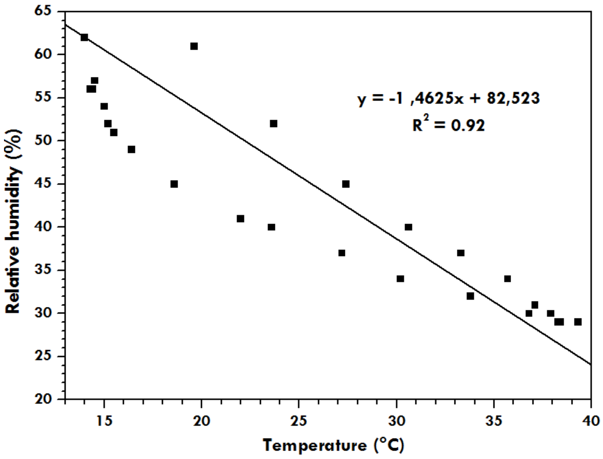
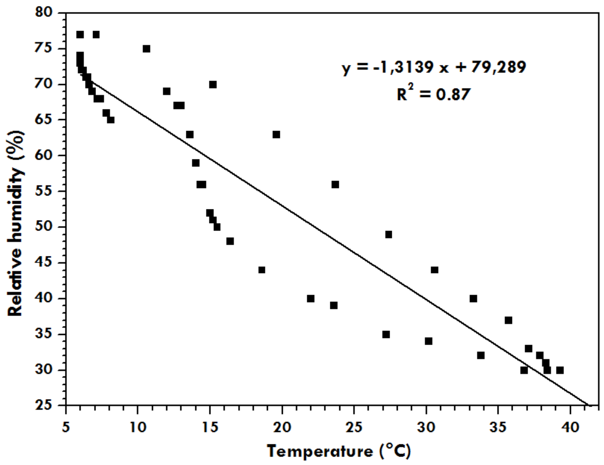



**Figure 10. Relative humidity gaps inside experimental and classic greenhouses**

Figure 11 illustrates the relationship between measured relative humidity and temperature in greenhouses. The relationship between these two parameters shows a strong hygro-thermal link. Figures 11a and 11b (measured values and linear regression curves) show that the slopes of the regression lines are negative in both the heated and classic greenhouse with a correlation coefficient ($R^2$) of about 0.87 and 0.92 respectively. Furthermore, it follows that the variation in the temperature/relative humidity ratio is inversely proportional and almost linear, which can be explained by the fact that the air water content is globally invariant.




**a) Classic greenhouse**




**b)Heated greenhouse**

**Figure 11. Relative humidity variation as a function of temperature**

Evaporation from the soil and evaporation in vegetation impregnated the rate of water increase. Thus, it is clear that the water vapour in the air reaches saturation point during the night period, resulting in high humidity in both greenhouses. The atmosphere in the control greenhouse is almost saturated with water vapour compared to the experimental greenhouse. During the day, this is due to the recovery of heat stored in the rock-bed. This helps to increase the air temperature in the experimental greenhouse and thus reduce water vapour.

The performance of the greenhouse equipped with a heating system was evaluated in terms of thermal load leveling, TLL, using equation (1). TLL was used to quantify temperature fluctuations within the greenhouse. In winter, the TLL is expected to have lower values by increasing the minimum temperature due to the incorporation of a heating system resulting in an increase of (T indoors,max + T indoors,min) as well as a decrease of (T indoors,max - T indoors,min) relative to greenhouse control.

Figure 12 presents the results of the daily variation of the thermal load level with and without heating system during the days of January 2017. It can be seen that the TLL value is maximum for a greenhouse without storage and is reduced by about 19% compared to a greenhouse with storage. These results show that during the night, if the indoor air temperature exceeds the optimal growth value by about 10°C, the fluctuations become small.

These results are consistent with other research evaluating greenhouse heating. Bazgaou [23] reported that high TLL values are observed in the unheated greenhouse compared to the heated greenhouse where indoor air temperature fluctuations are reduced by 13% during the measurement period in March. Bouadila [6] showed that the TLL value is maximum for a conventional greenhouse and that its value is reduced by 25% when the greenhouse is insulated. Berroug [25] indicated that the TLL value is maximum for greenhouses without PCM and that it is reduced by about half on average for greenhouses with PCM.

The lower thermal load leveling values indicate a decrease in fluctuations in the greenhouse air and therefore an improvement in the desired plant environment in the greenhouse.

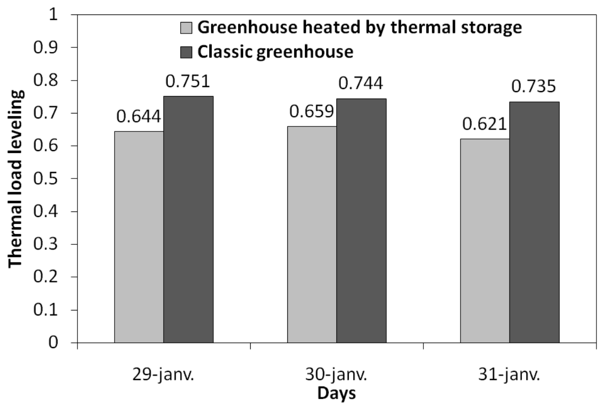



**Figure 12. Thermal load leveling of experimental and classic greenhouse**

The heating system equipped with a rock-bed placed under the surface of the greenhouse allows an increased air temperature and a decreased of the relative humidity of air during the night, due to the heat which was stored during the day and then released into the greenhouse by convection. At night, the heat of the gravel is transferred by convection to the air inside the greenhouse, which reduces the temperature inside the rock-bed and is then replaced by cold air; the latter will be recuperated during the day to cool the air inside the greenhouse.

This rock-bed system also creates favorable conditions for the good development of the plant (the optimum range of temperature and humidity) which affects positively the quantity and quality of the crop. This fit well with the results found by Gourdo et al. [26] and Adams et al. [27] who had proved that the growth of crop was seemly affected positively following the improvement of temperature at night.

To highlight the efficiency and performance of the proposed thermal storage system, the results obtained were then compared to those found by other researchers. In the work carried out by [28], a similar study examined a heating system with an underground rock reservoir in the greenhouse, benefiting from the improvement of the temperature in the greenhouse with a rate of 1°C to 2 °C, and a decrease of about 3% in the relative humidity inside the greenhouse. During the night, compared to the controlled greenhouse. In [29] the authors used a heating system with a pebble bed, where they had observed that the night temperature in the heated greenhouse is increased with a rate of approximately 2.6 °C, compared to the control greenhouse.

Conversely, our system is less efficient than in using two channels filled with compact greenhouse rocks [12]. However, the drawbacks of the latter system are that it can be set up in a large volume tank containing a large amount of rock drum and fans consuming a lot of energy. The disadvantages of the water heating system can also be clarified on several points, including: reducing the utilization of the area planted in the greenhouse and the possibility of the fragility and deterioration of the materials used (plastic pipes and barrels) with limited service life for several agricultural cycles. However, Gourdou et al. [26] stressed that the diameter of the sleeves used must not exceed 32 cm, in order to not hindering the movement of workers and machines among crop rows.

These systems have not achieved the performance of boiler heating systems [6, 15]; one of the disadvantages of these systems is the high purchase price and high-energy consumption of up to 1 l of fuel/m²/year [30]. Whereas, the consumption of heating per hour in a greenhouse with heat pumps from January to March was about 0.22-0.56 MJ/m², compared to the heating system with kerosene ranging from 31e55 g/m² to 0.76 MJ/m² [31]. In contrast, CO2 emissions per hour are around 9.5-24 g/m².

To improve the efficiency of the solar heating system, it is necessary to increase the size of the rock-bed used to store energy inside the greenhouse during the day. However, the depth of the system used should not exceed 70 cm, in order to avoid the difficulty of work and installation and to facilitate the maintenance process, if any. To overcome this dilemma, more research should be done on other heat exchange materials in order to increase the energy released in the greenhouse at night.

It can be noted that the system using a rock-bed, built into the greenhouse floor, is particularly interesting, since it contributes to heating the daily air of the greenhouse and positively contributes in preserving the environment.

The overnight temperature increase highlights the performance of the proposed thermal storage system. The available information (location, floor area and covering materials) of the greenhouses allowed for a comparison of results in terms of performance based on similar climatic conditions (Mediterranean climate) and the type of sensitive thermal storage. Table 5 summarizes results regarding the performance of greenhouses using sensible thermal storage.

**Table 5. Performance of various greenhouses using sensible thermal storage**

| Ref | Location | Greenhouse area | Storage type | Performance |
|---|---|---|---|---|
| Bargach et al. [32] | 36° 59′ N 2°50′ W, Rabat, Morocco | 250 m² | Flat plate collectors | 1.2 °C |
| Bezari et al. [11] | 36° 39′ N 3° 5 ′ E, Baraki, Algeria | 200 m² | Water tanks | 1.7°C |
| Bazgaou et al. [28] | 30° 13′ N, 9° 23′ O. Agadir. Morocco | 165 m² | Rock-bed | 2.6 °C |
| Gourdo et al. [29] | 30° 13′ N, 9° 23′ O. Agadir. Morocco | 15 m² | Rock-bed | 1-2 °C |
| Currently work | 32° 36' N 3° 51' E Ghardaïa, Algeria | 192 m² | Rock-bed | 3.2 °C |

## 5. CONCLUSION

This paper presented an experimental study to design and to realize a new thermal storage system in the form of a rock-bed in a greenhouse. The work was based on studying the effect of solar thermal heating on microclimate, plant growth, and agricultural yield under the experimental greenhouse. Therefore, an experimental analysis of the system's efficiency in the greenhouse was compared to greenhouse classic.

The results of this study showed that the solar greenhouse heating system was effective in improving the local climate and zucchini productivity. The temperature during the day was reduced by 5°C. In addition, the greenhouse air temperature was increased to 3.2°C at night and the relative humidity was reduced by 9.6%. The lower thermal load leveling values indicate a decrease in fluctuations in the greenhouse air and therefore an improvement in the desired plant environment in the greenhouse. This improvement in the climate inside the greenhouse during the cold winter nights had a major impact on the yield and quality of the zucchini, which was improved by 34%.

The storage of sensible heat in rock-beds doesn't harm the environment; moreover, it is sustainable and suitable for different sites and different greenhouses' types. Future studies should focus on the thermal modeling of the greenhouse with thermal storage in rock-bed, as well as the use of another form of energy storage to allow effective improvements in the thermal needs of plants.

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## ИСТРАЖИВАЊЕ И УНАПРЕЂЕЊЕ СОЛАРНИХ СТАКЛЕНИКА КОРИШЋЕЊЕМ ПАМЕТНОГ МАТЕРИЈАЛА ЗА СКЛАДИШТЕЊЕ ТОПЛОТЕ

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Стакленицима је потребна енергија да би током зимског периода стварали одговарајућу климу за производњу усева. Обновљива енергија је адекватан и одржив извор енергије за загревање стакленика. Циљ рада је да се истраже могућности побољшања климатских услова унутар стакленика коришћењем паметног материјала за складиштење топлоте. На основу експерименталних испитивања упоређени су резултати добијени за контролни и загревани стакленик у полу-сушној области. Израђен је нови пројекат стакленика са економичном каменом подлогом са паметном техником загревања за систем грејања у интегрисаном каналу H облика. Вишак дневне топлоте акумулиран у стакленику складишти се у систем и користи за ноћно грејање. Добијени резултати показују да је овај систем складиштења топлоте ефикасан и побољшава климу у стакленику. Ноћна температура је повећана за 3,2 $^{0}$C док је релативна влажност смањена за 9,6 % у поређењу са стандардним стаклеником.