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Statistical Study of Seasonal Storage Solar System Usage in Iran

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A B S T R A C T

The Seasonal storage solar systems set for greenhouse use, are capable of storing thermal energy in summer and use it in winter with special capacity. The main component of the system consists of solar thermal collectors and a sensible heat storage device which is buried under soil and uses water as storing media. The main aim of this study is to investigate the possibility of using this system in Iranian greenhouses, regarding the criteria that affected the system performance. This is also compared with same systems in Shanghai and Lisbon. This case study focuses on Tehran, Shiraz and Urmia, which are cities chosen from different ecosystems. Applying Tukey grouping method, the study showed that Urmia and Tehran that are respectively from Iran's medium and great radiation, are the best places for establishing the system. At last, regarding the obtained results, the application of the systems in every part of Iran would be c possible.

1. Introduction

Seasonal Thermal Energy Storage (STES) are systems that absorb solar thermal energy in hot seasons and use this energy in cold seasons. These systems consist of solar thermal vacuum collectors for thermal absorption and a storage tank of hot fluids, buried under stratum of soil. Regarding the decrease of fossil fuels in the world and its weather pollution, the study on green and renewable energy is increased. Solar thermal energy is one of the best green and free energy sources. Seasonal storage solar system can be used for greenhouse heating in cold seasons or for energy backup in industrial or official structures.

One of the STES analyses is accomplished in Lisbon (capital city of Portugal). This system is a simple one with small dimensions, and focuses on the possibility and economical aspects of the system. It is optimized with the best heat transfer and tank dimension with the genetic algorithm [1]. The second case of STES is analyzed in Shanghai (capital city of china) [2] The Chinese system is more complicated than Portuguese system. Its main components consist of vertical U pipes that are buried under soil and act as the system heating backup. The purpose of this study is to peruse and compare the quality and quantity of this system, assessing the possibility of solar STES usage with high performance in Iran. This regards the efficiency criteria on absorption or storage of energy in any cities of Tehran, Shiraz, Urmia, Lisbon, and Shanghai. The following will explain this.

The 'sunshine hours" is the only large-term phenomenon which measured information is accurate and reliable. It is used to measure the accurate amount of solar radiation and also estimate it for the entire world. There are many investigations done on sunshine hours, humidity, latitude, and weather temperature to estimate solar radiation based on empirical models. Solar energy estimation with sunshine hours, in maximum temperature and humidity, for different zones of Egypt, Jordan, and Kuwait is done by Sabbagh et al [3], observing cloudiness and the zenith angle of sun. Paltridge and Proctor [4] measured direct and diffuse daily solar radiation for the entire world in theirs empirical models. This article uses their model to estimate solar radiation in the Iranian cities.

In this paper, statistically, the possibility of using STES in different regions of Iran is investigated. Statistically, Tukey method is used as a grouping criterion, and One-Way ANOVA technique is used to the determine source of difference

2. Introduce models

In this article, two different solar STES are used to validate usage possibility in Iran. The first system is analyzed by Dorão et al. [1]. It is a greenhouse heating system for 50kW heating load. The whole system is modeled applying a dynamic modeling tool and the sizing parameters that were optimized through a genetic algorithm process. According to it, this system can be used as a high solar fraction system, a greenhouse, building sector, or an industrial application (Figure.1). The second one is designed in China by Xu et al.[2] In the Chinese project, approximately 4970 m3 of soil is directly embedded under the greenhouse. It contains 130 vertical U-type heat exchangers that are located at a depth of 10m and store the excess solar heat captured in non-heating periods. The greenhouse was 48 m wide × 48 m long × 4.3 m height multi-span greenhouse (the width of each span is 9.6 m). It is covered with 4 mm float glasses. The plants were placed on the shelves which were 0.75 m above the ground. In the winter evenings, some shelves were covered with plastic film to reduce the heat loss (Figure. 2).

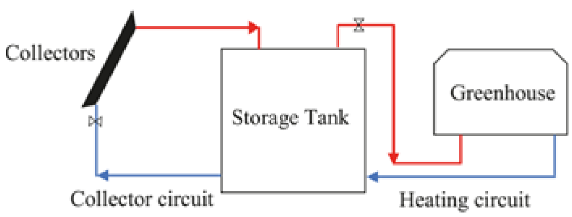

Figure 1: Portuguese solar system scheme [1]

1. Study effective criteria on absorption and storage of solar heat

The first model that estimated solar radiation on the horizontal surface is empirical model of Angstrom and Paltridge [7, 4]. It is based on sunshine hours.

$$\frac{\overline{H}}{\overline{H_0}} = a + b\frac{\bar{n}}{\overline{N}} \tag{1}$$

In Eq. (1), $\overline{H}$ indicates the average daily total radiation in each month. $\overline{H_0}$ shows measured solar radiation out of the atmosphere, which is obtained with Eq. (2). a and b are Angstrom coefficients that are empirical coefficients.

$$\overline{H_0} = 24 \times \frac{3600G_{sc}}{\pi}\left(1 + 0.033\cos\left(\frac{360n}{365}\right)\right. \times \left\{\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right\} \tag{2}$$

Here, G_{sc} is emission constant out of the atmosphere, which is 1373 w/m^2 in this paper, ϕ is attitude of special region, δ is declination ($-23.45° \leq \delta \leq 23.45°$), which is calculated with Cooper [9] equation (3). Also ω_s is the angle of sun clock in degree that is obtained from Eq. (4).

$$\delta = 23.45\sin(360\frac{284+n}{365}) \tag{3}$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \tag{4}$$

$$\overline{N} = \frac{2}{15}\omega_s \tag{5}$$

Where n is the No. of day from solar calendar ($=1$ is 21 March) for that day, $\bar{n}$ is the monthly average daily sunshine duration in hours, and $\overline{N}$ is the monthly average maximum sunshine hours in one day. It is calculated with Eq. (5).

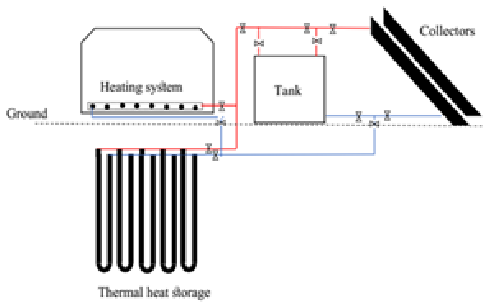

Figure 2: Schematic diagram of a solar heating system with seasonal thermal energy storage (Chinese model) [2]

4. Geographical study of the cities

Based on annual solar radiation, Samimi [16] divided Iran to four parts. This is reflected in Figure. 3: The region with low radiation has less than 14 MJ/m2 per day like the areas located under Caspian sea. The region with medium radiation has 14 to 16 MJ/m2 per day like Urmia, Tabriz, and Mashhad. The region with great radiation has 16 to 18 MJ/m2 per day like Tehran, Ahvaz, and Yazd. The region with so great radiation has greater than 18 MJ/m2 per day like Shiraz and Kerman.

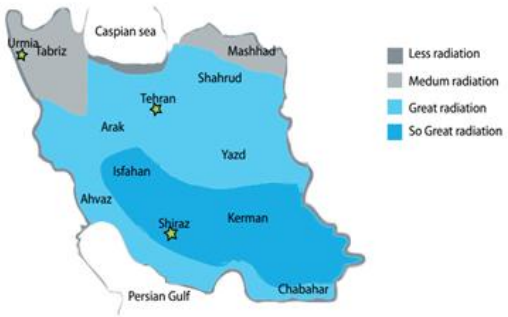

Figure 3: Iran solar radiation divisions [16]

5. Geographical study of the cities

For studying the possibility of solar STES in Iran two problems should be regarded. Firstly, choosing the sample city and, secondly, studying the criteria that affect its performance. In this paper, Urmia, Tehran, and Shiraz are chosen from different ecosystems of Iran. They respectively represent medium radiation, Great radiation, and So Great radiation [16]. The Angstrom coefficients for Shanghai, Lisbon, Urmia, Tehran, and Shiraz are obtained by an experimental study. They are represented in the following Table 1.

Table 1: Angstrom coefficient for Shanghai, Lisbon, Urmia, Tehran and Shiraz

	Shiraz	Tehran	Urmia	Lisbon	Shanghai
a	0.317	0.346	0.402	0.303	0.18
b	0.405	0.343	0.305	0.303	0.55
Ref.	[10]	[10]	[10]	[12]	[11]

$\bar{n}$ in Eq. (1) is the monthly average of daily sunshine duration for the Iranian cities and it is taken from the synoptic station website (West Azerbaijan Meteorology [13]). That of Shanghai and Lisbon is taken from (Current Result [14]) an official website.

$\bar{N}$ that is the monthly average maximum sunshine hours in one day, depends on the angle of sun clock which is calculated with Eq. (5) and (6).

$$\omega_s = 15 \times (12 - t) \tag{6}$$

In Eq. (6), t is the angle of an hour for one day. For example, at 14:00 o' clock, this angle is $-30°$. In this paper, the formula of$\omega_s = -30° \rightarrow \bar{N} = 4$ is used to study the related effects.

Angstrom coefficient and $\bar{n}/\bar{N}$ from Eq. (1), and $\bar{H}/\overline{H_0}$ for the cities in one year from Figure. 4 show varying non-dimensional values of solar radiation in different cities.

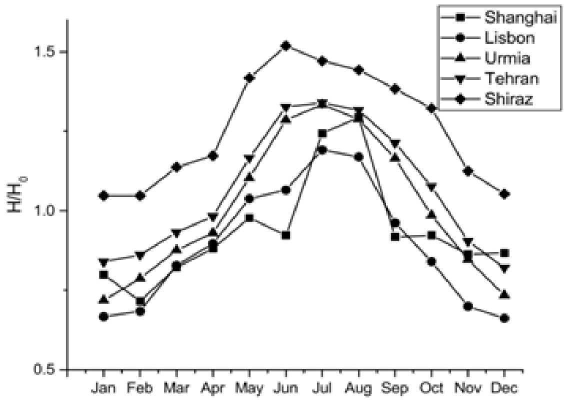

Figure 4: Radiation coefficients for the cities

To calculate $\overline{H_0}$ (solar radiation out of atmosphere), Duffie and Beckman [8] accomplished a study on cosmic Equation of solar radiation, as represented in Eq. (7)

$$\overline{H_0} = 24 \times \frac{3600 G_{sc}}{\pi} (1 + 0.033 \cos\left(\frac{360n}{365}\right) \times \{\cos\phi \cos\delta \sin\omega_s + \frac{\pi\omega_s}{180} \sin\phi \sin\delta\} \tag{7}$$

In Eq.(7), $G_{sc} = 1373$, $\omega_s = -30°$ and δ is the special amount for each cities.

The geographical locations of Shanghai, Lisbon, Urmia, Tehran, and Shiraz are extracted from (Bing map, 2015[15]). They are reflected in Figure. 5 and Table 2.

Figure 5: Geographical location of the cities

Table 2: Longitude, Attitude and Altitude of the cities

	Longitude	Attitude	Altitude(m)

Shanghai	$120^o\ 30^'$	$31^o\ 12^'$	13
Lisbon	$9^o\ 8^'\ 21.79^{''}$	$38^o\ 42^'\ 49.72^{''}$	199
Urmia	$45^o\ 4^'\ 21^{''}$	$37^o\ 33^'\ 19^{''}$	1332
Tehran	$51^o\ 25^'\ 23^{''}$	$35^o\ 41^'\ 46^{''}$	1190
Shiraz	$52^o\ 32^'\ 36^{''}$	29o 37’ 02”	1480

Table 3: n and δ parameters of duration of one year

	Jan	Fe	Ma	Ap	Ma	Ju	Jul	Au	Se	Oc	No	De
n	30	33	36	26	56	87	11	14	17	20	24	27
δ	-	-21-	-	-	-	2.418	13.62	21.43	23.29	18.91	9.230	-

Table 3 shows the declination δ in Eq. (3) that is calculated based on the 15th day of each month. Figure. 6 also, shows $\overline{H_0}$ that is the cosmic properties of the cities. $\overline{H}$ shows the monthly average daily radiation as shown in Figure. 7. The annual average of solar radiation per day as one of the comparison parameters for the cities as well as the calculation of it for the hot month of a year per day are shown in table 4.

Table 4: Annual average of solar radiation per

	Hot months (Mar, Apr, May, Jun, Jul, Aug)(Mj/m^{2}day)	Annual average(Mj/m^{2}day)
Shanghai	15.893	14.453
Lisbon	14.651	12.573
Urmia	16.408	14.278
Tehran	17.415	15.622
Shiraz	21.556	19.821

The annual average of solar radiation per day is not a sufficient criterion for comparing the cities. Therefore, ANOVA test of solar radiation and using grouping information criteria are the best choices for analysing the differences in group means and varieties. The result tables of 5, 6, and 7 are analysed with One-Way ANOVA method in Minitab.

Table 5: Results of One-Way ANOVA method

Source	DF	Sum of Square	Mean Square	F	Sig.
Data	4	3.54802×10^{-14}	8.87006×10^{-13}	11.3	0
Error	55	4.31686×10^{-14}	7.84883×10^{-12}		
Total	59	7.86488×10-14	-		

Table 6: Individual 90% confidence interval for Mean based Pooled

Level	---+---------+---------+---------+------
Lisbon	..(---*---)………………………………..
Shanghai	……..(---*---)…………………………..
Shiraz	………………(---*---)………………….
Tehran	……….(---*---)…………………………
Urmia	……..(---*---)…………………………...

standard deviation

The statistical study of solar radiation in Shanghai, Lisbon, Urmia, Tehran, and Shiraz with 95% confidence reveals difference among the cities and the possibility of using same system for all of them. According to table 5, p - value = 0.00 represents a significant difference in the annual solar radiation of the cities. To distinguish this difference and its source and grouping, Tukey method is used. Regarding the results of Tukey method in table 7, it is clear that Shiraz has significantly a different solar radiation level from the other four cities. Referring to confidence interval chart in table 6, Urmia, Shanghai, Lisbon, and Tehran were in same statistical group and, approximately, had similar solar radiation for a better vision The table shows that Shanghai, Lisbon, Urmia, and Tehran, with 95% confidence, have interference, but Shiraz is distinct from them. Regarding the altitude of the cities mentioned in table 2, Shiraz, Urmia, and Tehran are in a higher see level than Shanghai and Lisbon. It also shows that these cities have a better level in solar radiation than Shanghai and Lisbon. It is also possible to apply the formula and models of a group of cities for the other group. For example, the results of Tehran and Urmia can be attained by the same model used for Shanghai and Lisbon, regarding casts, premium, and benefits.

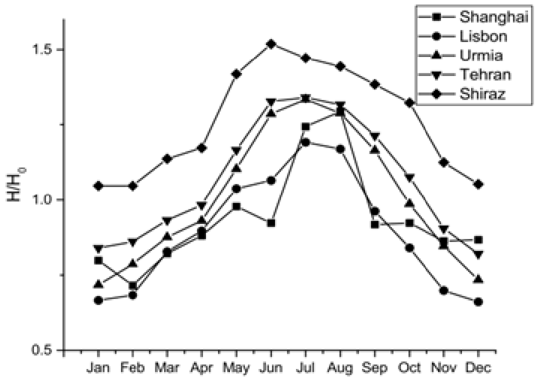

Figure 6: Measured solar radiation out of atmosphere

Table 7: Grouping information using Tukey Method (confidence

	N	Mean(J/m^{2}day)	Grouping
Shiraz	12	19826189	A----------
Tehran	12	15621988	-----------B

Shanghai	12	14453142	-----------B
Urmia	12	14378512	-----------B
Lisbon	12	12573205	-----------B

The three Iranian cities are chosen from three different regions with different solar radiation. Though Urmia has a lesser radiation than the other two cities, but its radiation is greater than Lisbon's and almost equal to Shanghai's radiation. This means that, approximately, the entire of Iran has a better condition in solar radiation and the performance of solar STES would be better there.

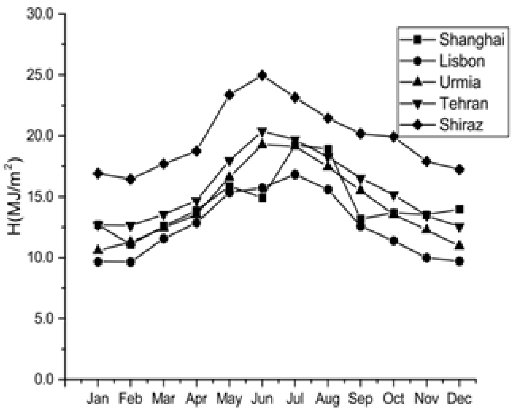

Figure 7: Monthly average of daily solar radiation

6. Conclusion

Seasonal storage solar systems are capable of storing thermal energy in summer and using it in winter, with special capacity. The main component of the system consists of solar thermal collectors and a sensible heat storage device which is buried under soil and uses water as storing media. The purpose of this study was to investigate the application of this system in Iranian greenhouses, with a focus on the criteria that affected the system performance. To study the possibility of solar STES usage in Iran, the chosen candidate cities for calculating solar radiation in Iran are very important. In this paper, three cities from different ecosystems and with different solar radiation were chosen. Considering the results of the past studies, the second important thing is the statistical comparison method chosen for the distinct groups of cities.

Results of the presented study can be summarizer as follows:

- Solar radiation difference between the cities is analyzed by using One-Way ANOVA. The source of difference is determined by Tukey method.
- The Iranian cities of Urmia and Tehran are in one group with Shanghai and Lisbon. Shiraz is not in the group.
- Statistically, with 95% confidence in Urmia, Tehran can use the systems that are used in Shanghai and Lisbon.
- Shiraz has significantly different solar radiation condition compared to the others.
- Shiraz in either cases of annual average of solar radiation or grouping information has a much higher radiation.
- Because the cities are chosen from different ecosystems in Iran, this let's generalize the results to all parts of Iran.

All the regions in Iran can use solar seasonal storage system because Shanghai and Lisbon with less radiation can also use this kind of system.

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