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OPTIMAL DESIGN AND CONFIGURATION FOR PASTEURISING HEAT DEMAND SUPPORTED BY SOLAR THERMAL SYSTEM USING T*SOL SOFTWARE

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Abstract: While milk is the most consumed human drink, industrial food processes exist everywhere. It consumes a massive amount of hot water at moderate temperature levels, essential to generating the final product. The integration of small and medium enterprises (SMEs) with solar thermal systems creates noticeable savings in fuel and electricity. Identifying the integration system employed can be solved using innovative engineering simulation tools like T*sol. And the maximum points and configuration can be adjusted to achieve the maximum solar yield. This paper compares the middle east and central Europe for a medium-size pasteurising plant with an average daily consumption of 20 kWh and an annual energy requirement of 7.3 MWh. The processed heating system is supported parallelly with a 25 kW boiler for two main cities, Damascus and Budapest, with different standard collector types, FPC, ETC, and CPC. It shows that for a small-medium-sized pasteurising plant with 20 kWh daily consumption, a solar system consists of 30 m^2 and 20 m^2 for Budapest and Damascus. With the performance of annual solar fraction 64% and 82%, and total system efficiency 14.9% and 17.2%, respectively. It shows the importance of having solar thermal technologies in the abovementioned regions.
Keywords: Solar thermal system, pasteurisation, solar fraction, heat process

1. INTRODUCTION

During the recent decades, the increased ambient temperature has been noticeable worldwide due to the carbon dioxide and greenhouse (GHG)s emissions caused by the impact of fossil fuels [1]. Moreover, since space heating and all industrial processes need hot water, solar thermal energy can take part and reduce GHG emissions [2,3]. The solar thermal system has the advantage of not needing a large amount of water compared to geothermal or biofuel systems [4]. It needs just a space like the unutilised rooftop or some square meters on the ground. A low-maintenance solar thermal system can give enough energy directly once installed.

A substantial amount of heat energy demand can be obtained from solar thermal systems for industrial and agri-food processes[5]. At the same time, milk is the most consumed human drink and processed and pasteurised in the daytime, making a matching profile with solar energy. Knowing that 77% of the energy needed in Agri-processing is for heating processes (60% of the required heat is below 250℃) regarding less the geographical location [6]. While up to 400℃ steam or hot water can be supplied in developed economies, giving the chance to cover about half of the national energy demand. Adding to the fact that the demand variation in industry sectors like food, textile, brick [7], and agriculture processes match the supply variation in solar thermal energy, making it suitable for drying, washing, dyeing, and boiling pasteurisation and sterilisation [8]. However, several standard solar thermal technologies are mainly three types: air collectors, water collectors, and concentrators. Traditional solar collectors (125-250 C) are the best solutions for the low-medium temperature range. Such as flat plate collector (FPC), or evacuated tube collectors (ETC) [9], which gives not less than 60% solar fraction for domestic hot water at 55℃, are mainly used in residential applications [8]. However, the mid-range temperature can be used in an industry where those collectors are mostly made locally. For example, in Turkey or China, the prices are lower 3-10 times than in the USA and EU [10].

In the food and beverages sector, 3.3 and 2.2 EJ need low and medium-range temperatures, respectively, creating thousands of new vacancies annually [11]. Nevertheless, it is evident from statistics that only 1% of the solar thermal technologies' utilisation is used in industrial processes [12] because there is a mismatch between the prompt demand in the supply and the sporadic nature of the solar energy [13,14], which makes this energy inappropriate in some industrial cases.

2. SOLAR HEAT FOR INDUSTRIAL PROCESS (SHIP) SYSTEM

Food and paper industries have the highest heat demand, similar to chemical and textiles, which also have considerable need. For the most part, the utilization of the solar thermal system in industrial applications has a rapid growth from 42 MW in 2010 worldwide with an estimated area of 60000 m^2 [15] to 93 MW in 2014 with more than 136000 m^2. Most of these projects have less than 1000 m^{2,} and 70% use ETC and FPC. Utilizing FPCs and ETCs means a substantial amount of the demand energy is achievable from a middle-sized solar field [16]. The deployment is increasing, but the geographical market, where the last reports showed with approximately 20 projects in 2017 in many countries like Germany, Greece, Italy, Spain, and the USA. In addition to this, India led this awareness by 61% of its solar thermal systems capacity employed in process heat industrial systems. Furthermore, the Middle East and the Arabian Peninsula have a high potential for market growth, especially oil refineries [17].

In most industrial products' manufacturing processes, heat is essential with a wide range of temperature demands and different sectors in different countries. The heating process is obtained by either fuel, steam, electricity, or many combined sources. Regardless of the chosen method, a tremendous amount of energy is always needed. Moreover, two main types of heating processes are available: direct and indirect, where the direct method is the generated heat at the process place, like microwave or induction. While the indirect method is when the heat must be transferred to the process place, usually through a heating fluid liquid, on the other hand, another classification is concerning the temperature range [18], where the low temperature is usually used for rinsing, washing, and food processes. While for space heating and domestic hot water, Mid-range temperature is needed for drying and evaporating. Thirdly, a high temperature is required for heavy industries like ceramics and metals.

3. METHODOLOGY AND SYSTEM DESCRIPTION

Two main concepts are integrating the solar system with an available process heat. Either integrate it directly into the process heat and have a parallel supporting boiler. Or to have an indirect heating system where the heated up water must inter the boiler to ensure its temperature before reaching the heat process, which means no direct connection between the solar system and the industrial process heat. The supposed direct system integration, as shown in Figure 1.

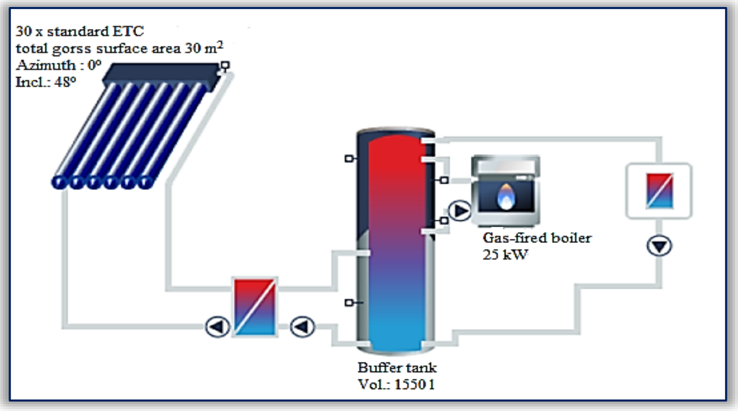


Figure 1. A direct solar thermal system with a buffer tank for the heat process

4. RESULTS AND DISCUSSION

T*sol provides a high level of accuracy with more convenient interface programming and configuration [19,20]. Unlike Trnsys and other programs, T*sol has here the lead. It noted for SMEs that Each pasteurising profile is from (6 AM to 4 PM) repeated daily during the whole year. Furthermore, there might be many milking batches per day; usually, the milk is stored until the next day to be processed, as in Figure 2. The load profile is constant.

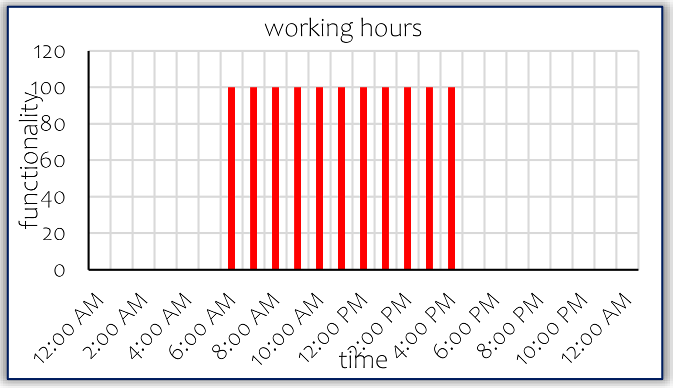


Figure 2. Pasteurising working profile.

The examined variables are according to the following matrix. We analysed two cities with the same pasteurisation demand by changing three standard types of collectors: FPC, ETC, and CPC with changing apparatus area of 5 to 100 m. The chosen collectors are not industrial types, but standard ones and the main characteristics are in Table 1. The specific heat capacity states the amount of the heat per square meter of active solar surface that the collector with its heat transfer medium content can store at a temperature increase of 1 Kelvin. At the same time, the conversion factor in per cent represents the absorbed vertical radiation over the collector surface area.

$$\begin{pmatrix} \text{Damascus} & \text{FPC} & 5 \\ & \text{ETC} & \vdots \\ \text{Budapest} & \text{CPC} & 100 \end{pmatrix}$$

Table 1. Solar collector specifications

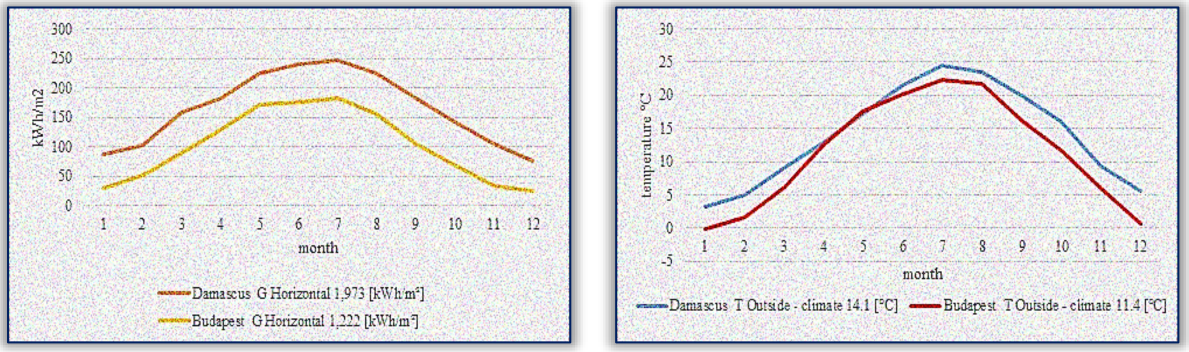
Type	Gross surface area [m²]	Specific heat capacity [Ws/m². K]	Conversion factor [%]	Linear heat transfer coefficient [W/m². K]	Quadratic heat transfer coefficient [W/m². K²]
FPC	1	6000	78	3.8	0.03
ETC	1	8000	70	1.8	0.02
CPC	1	6000	64.6	1.016	0.002

Finally, the linear and quadratic heat transfer coefficient describes the collector's heat amount released to the surroundings per the active surface area square meter. Considering that the temperature difference between the collector median temperature and the environment is Kelvin. While it is evident that the linear part multiplied by the simple temperature difference, similarly the quadratic by the square difference, the results are typical parabolic efficiency curves.

The collectors' installation oriented southerly since both Syria and Hungary are located in the northern hemisphere with 0^0 azimuth angle, which means direct orienting toward the south and perpendicular to the equator. The slope angle was determined according to the solar electricity handbook 2019 edition, where 48^0 concluded for Budapest and 34^0 for Damascus and the weather comparison data in Table 2. The weather data shows 61.4% more annual irradiation for Damascus, as in Figure 3a, which gives the privilege for solar projects. While the average daily temperature shows lower climate conditions for Budapest as in Figure 3b, above all, the subtitle Kmi and Nabk illustrate the exact location near the two cities, where metrological data sites are stored simulation calculated accordingly.

Table 2. Weather data comparison.

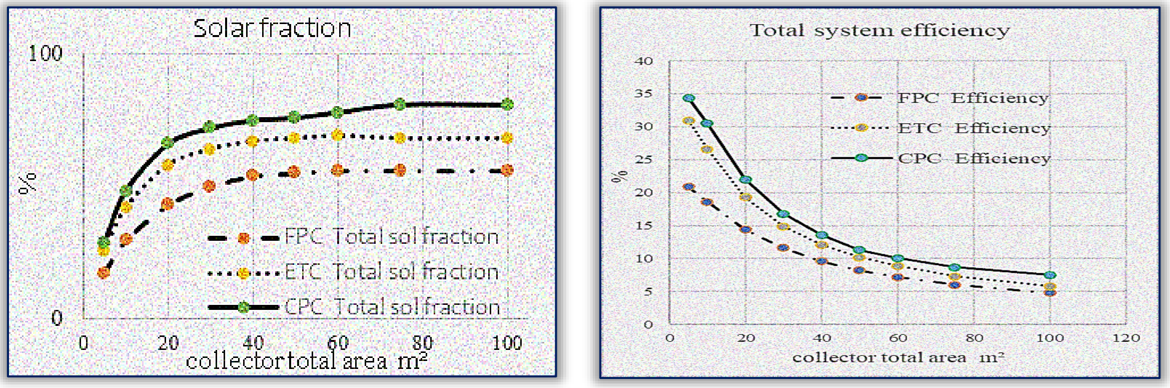
City	latitude	longitude	total annual global irradiation	diffuse radiation percentage	mean outside temperature	lowest outside temperature
	[^{0}]	[^{0}]	[kWh/m^2]	[%]	[°C]	[°C]
Budapest-kmi	47.5	-19.0	1222.4	52.80	11.4	-11.7
Damascus_Nabk	34	34	1973.2	41.1	14.1	-5.9



(a) (b)

Figure 3. (a) solar radiation on a horizontal plane and (b) monthly average temperature

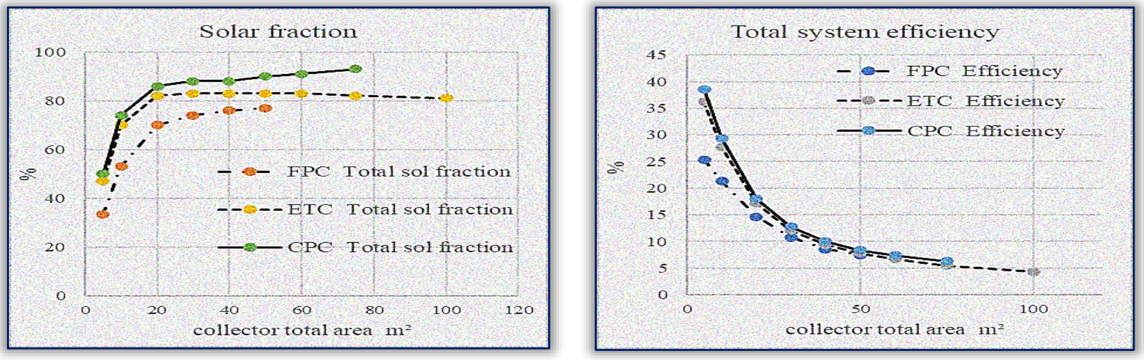
Moreover, the optimal solar collector total area regarding the whole system efficiency and the solar fraction for Budapest city is between the interval 20 – 40 m^2 as in Figure 4. After this interval, the solar fraction tends to be more stable. Or sometimes slight changes or even some dropping down, like in the case of ETC for 60 and 75 m^2. In these two cases, the solar fraction falls from 68% to 67%, which means the added area has a neutral or negative influence on the whole system's performance. This exotic result is that this system has no simple method to calculate the solar system yields precisely because the number of parameters that determine the system performance is too large and includes non-linear changeable weather data and dynamic solar system processes. Besides, another note is that the system efficiency is falling significantly due to larger solar tank capacity, which is exposed to the surroundings and the internal and external connection pipes. Clearly, after the interval between 20 - 40 m^2, the system tends to stable mode again. Comparing the three collectors' types, the CPC has a better result regarding both solar fractions. The optimal result reaches up to 72% compared to 64% and 50% for ETC and FPC, respectively. Furthermore, for the system efficiency, up to 16.8% for CPC compared to 14.9% and 11.6% for ETC and FPC, respectively. All those results were calculated at a 30 m^2 collector optimal area.



(a) (b)

Figure 4. (a) Budapest optimal system solar fraction and (b)Total system efficiency

A similar discussion about Damascus conducted for more likely 10–20 m^2 intervals signifies the optimal case in Figure 5. The system solar fraction performance tends to be stable after 20 m^2, which means no added value to the system by adding more collectors. It noted for FPC that the simulation could not run after 50 m^2 because of exergy analysis issues, which represents energetic problems similarly to ETC for more than 75 m^2. Undoubtedly the optimum chosen case is 20 $m^{2,}$ where the solar fraction for CPC, ETC, and FPT are 86%, 82%, and 70%, respectively, while the whole system efficiency is 18%, 17.2%, and 14.6%, respectively.

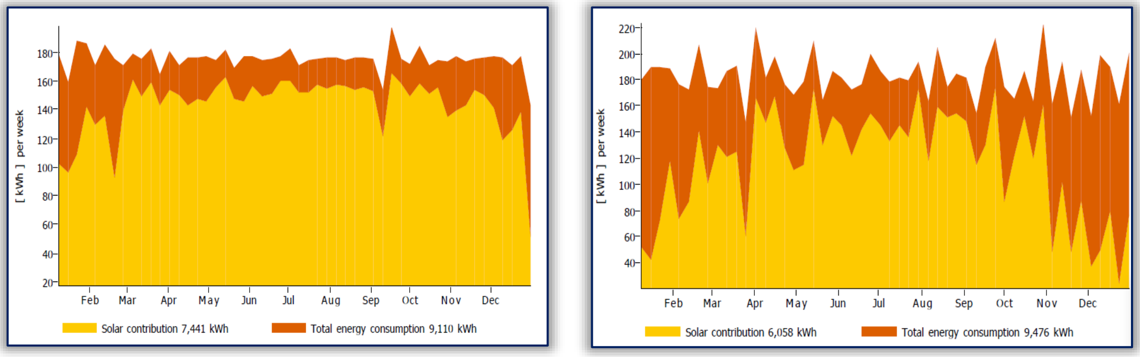


(a) (b)

Figure 5. (a) Damascus optimal Damascus system solar fraction and (b) total system efficiency

Choosing the final design is not enough to detect the best performance because of many obstacles. The obstacles can be the availability of this collector in the market, the price of the collector per square meter [6], and the critical point of those collectors that it is a standard one, which means a difference between the properties of these collectors compared to commercial ones—besides, the cost estimation of the collector types. As noted, FPC is the cheapest 150 €/m^2 but, with lower performance, and the average price of ETC 340 €/m^2 compared to 245 €/m^2 for CPC including mounting and piping system. Even though the CPC is cheaper 38.77% than the ETC, still ETC is more available in the market. Moreover, it remarked in Damascus case that the ETC and CPC are close in performance as 86% and 82% solar fraction and the system efficiency 18%, 17.2%. However, another thermal perspective will be taken into consideration that the maximum output temperature of FPC is 80-100℃ for a standard collector, While ETC and CPC reach up to 200 ℃ and 240℃ respectively. Subsequently, the ETC is chosen for its appropriate thermal range and availability in both markets.

The optimum Budapest system has an overall efficiency of 14.9%. It is low due to many issues, mainly optical solar collector losses, boiler efficiency, and total heat losses from tanks and connection pipes. The assumed data regarding the connection of the pipes is 8 m in the building and 1 meter outside, with both thermal insulation 0.045 W/m.K with spacing between collectors 20 cm. While the velocity inside the tubes is 0.5 m/s, those factors significantly influence the system performance and total system efficiency, so they must be identified and discussed in further research. The overall solar fraction is 64% while it reaches up to 80% for both July and August, and the lowest surely will be for January and December 39% and 28% respectively as in Figure 6.



(a) (b)

Figure 6. Solar energy consumption as a percentage of total consumption (a) Damascus and (b) Budapest

Simultaneously, the Damascus case shows 82% total solar fraction with a total system efficiency of 17.2%. The solar fraction is more than 80% from March to November, while the lowest is 68% and 62% for January and December. It illustrates the importance of having such projects in the Middle East regarding the high solar irradiation. Another note of the detailed schedule information is that the solar system provides more energy than the energy provided from the boiler in all the months. The CO_2 emissions avoided in Damascus is 2.746 tones while Budapest was 2.235 tones.

From the average and mean outlet temperature profile, it is not noticeable if the collector outlet temperature is fulfilling the temperature need. In contrast, this information is observed clearly in an annual supply temperature at the primary heat exchanger side, as in Figure 7. It is noted that the maximum average temperature reaching is approximately 88.9 ℃ for Damascus and 78.3 ℃ for Budapest. If we look deeper in daily profiles, many days can have more than the needed temperature, which means mixing and cooling down the output water from the tank is needed before the heat processing starts. This high temperature can be utilized to clean in place (CIP) processes where steam or high temperature is preferable.

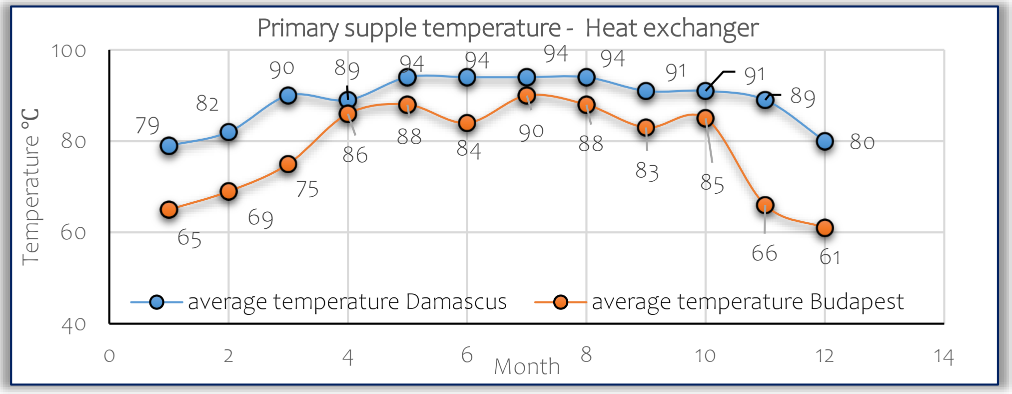


Figure 7. Average monthly heat exchanger supply temperature

To understand the low system efficiency, the exergy analysis conducted to illustrate the system's low efficiency, as in Figure 8, compares the valuable energy from both solar collectors and the boiler as inputs and the process heat as output. In Table 3, even though Damascus has 20 m^2 compared to Budapest 30 m^2, the solar energy provided to the whole collector system is higher for Damascus due to the higher solar radiation, the same for the energy coming from the collectors as in legend 2.

Tank losses in the Budapest case are higher due to the bigger size volume tank and larger exposed area, which causes more heat losses.

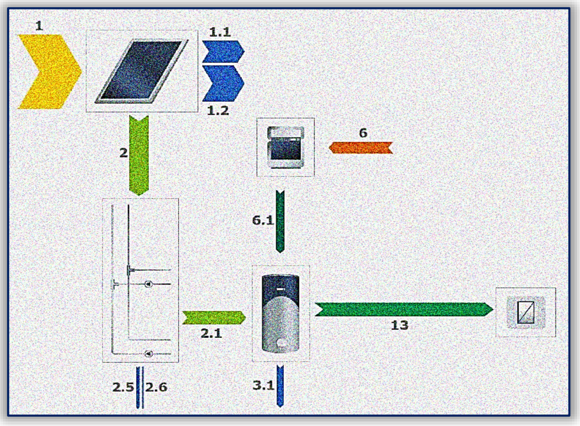


Figure 8. Exergy analysis of the system performance

Table 3. Energy balance schematic.

Legend	Name	Budapest [kWh]	Damascus [kWh]
1	Irradiation on the collector surface	40,733	43,337
1.1	Optical collector losses	11,976	11,643
1.2	Thermal collector losses	19,741	21,032
2	Energy from collector array	9,017	10,662
2.1	Solar energy to storage tank	7,063	8,403
2.5	Internal piping losses	1,557	1,849
2.6	External piping losses	397	409
3.1	Tank losses	3,178	2,808
6	Final energy	6,220	3,044
6.1	Supplementary energy to tank	3,418	1,669
13	Tank to process heating	7,300	7,300
Total system efficiency		14.9%	17.2%

The savings in CO_2 emissions or natural gas are 2.746 tones in Damascus, while 2.235 tones in Budapest. These two indicators are not a significant share of the total country's emissions (Syria more than 34 million and Hungary more than 50 million annually), but still, when SMEs moves toward sustainable and renewable resources, the total number of the annual emissions will be significantly reduced.

5. CONCLUSIONS

In this study, two pasteurising plants in the Middle East (Damascus, Syria) and central Europe (Budapest, Hungary) simulated to find the appropriate solar thermal collector needed for the pasteurising process's heat demand. After evaluating the results, the following conclusion was found as the following:

— The overlapped profile of the solar energy radiation and the milk production period annually makes this energy suitable for providing a visible portion of the needed demand to a greater or a lesser extent. The location significantly affects the results due to the difference in the solar radiation between the two tested regions.

— For small to middle-sized solar fields can achieve energy demand of more than 50% for the Budapest case for eight months, while for the Damascus case, the whole year has a high solar fraction of more than 62%, while the boiler intervenes to substitute the rest of the heat demand.

— Even though the performance of the CPC has the highest results, the absence of this type from the local markets is the reason beyond that the ETC is the chosen type, because of the slight result difference between it and the CPC, adding to the high life span with no maintenance.

- We did not choose FPC even it is the cheapest solution because of the radiation nature in both cities, where 41.1% and 52.8% of the radiation is diffusive in Damascus and Budapest, respectively. In addition to the low output temperature range (below 100°C usually), it is unsuitable for this duty according to the output temperature profiles because the temperature can reach more than 100°C in the summer in both cities.
- The internal and external piping system and the insulation must be studied further since they significantly influence overall system performance.
- Since the mass production from the surrounding countries is flooding the market with cheaper products, the solar energy solution will reduce the cost of the product, which leads to better competitiveness of the local products.
- Even though the saving of the CO_2 and gas is not a significant share of the total country emissions, a considerable share of the emission will be reduced by directing more SMEs toward renewable energy.

Based on the results, additional parameters and more significant enterprises can be investigated for pasteurisation and other industries. These industries can be bulbs or chemicals and different factory and industry sizes, encouraging the solar heat process in the industrial sector.

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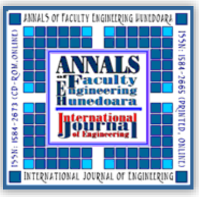

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