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Assessment of Greenhouse Heating/Cooling via Heat Pump for Herat-Afghanistan

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Abstract

Energy is an essential requirement for living, and the renewable energy sources are increasingly popular sustainable energy sources. The solar energy is an inexhaustible, clean, and sustainable energy source in the world. In this work, heating of a greenhouse in Herat (Afghanistan) with a heat pump is investigated using the solar energy. The greenhouse is kept at 20 ^{o}C, and the electricity required to operate the heat pump is taken from the grid. As a result of the analysis, the exergy/electricity input reaches 25.59 kWh, while the minimum value is equal to 0.01 kWh. It will be determined that the product exergy undergoes the maximum product exergy of 6.38 kWh. Finally, it will be determined that a ground source heat pump with a higher COP can be used instead of an air source heat pump.

Keywords: *Greenhouse, Solar energy, Heat pump, Herat-Afghanistan.*

1. Introduction

Energy consumption is a significant problem in the world [1-6]. The population growth, industrialization, and urbanization rapidly increase the energy demand. The increasing requirement for energy day by day increases the energy consumption in parallel [7-10]. The renewable energy sources are the primary, domestic, inexhaustible, and clean resources [11-18]. The demand for renewable energy sources such as solar energy has increased in the recent years [19-22].

Exergy is a valuable tool to distinguish between the internal irreversibility and the energy losses [23]. The energy sources and the exergy efficiency can be optimized using the unconventional optimization techniques [24-26]. Exergy analysis helps us better understand the energy-saving potential.

Several types of heating systems have been used in greenhouses in order to meet the heating and cooling supplies. These systems may usually meet the heating supplies of the greenhouse. Still, the temperature circulation shapes within the greenhouse related to such systems are readily influenced by the outside weather conditions. Therefore, it is of great importance to use a heat pump system for greenhouse air conditioning [27,28].

In this work, a greenhouse in Herat was heated and cooled by a heat pump in terms of its performance. The performance analysis was conducted in the transient conditions; it was performed daily. The availability/unavailability analysis was carried out using the exergetic approach defined in Section 4.

2. Afghanistan Location

Afghanistan is located in the South-Central Asian part of the Asian continent. It neighbors Iran from the west, Pakistan from SE, China from NE, and Tajikistan, Uzbekistan, and Turkmenistan from the north. Afghanistan is 652,864 km², and it is a mountainous country with no connection to the sea [29]. Due to its arid and semi-arid climate, its summers are hot, and its winters are icy [30]. In Afghanistan, the electrical energy is supplied either from the imports or from the domestic diesel generators. Though there are essential potentials for renewable energy generation in Afghanistan, they are used in slight quantities [31].

The city of Herat in western Afghanistan lies on the Harirud River, south of Paropamisus Range, at an elevation of 3,026 feet. Herat is one of the country's most densely populated and fertile agricultural areas [32].

3. System Description

The energy and exergy transfer between a greenhouse, energy source, and environment used in this work is given in figure 1. In the current work, the greenhouse heat loss was calculated using equation (1). The constant internal temperature of the greenhouse was taken as 20°C. The f_w, f_c, and f_s were accepted as one [33, 34]. While carrying out the calculations, the greenhouse gases were neglected. The heat resistance of the building material was taken as 0.28 m^{2}K/W. The greenhouse lateral area of 312 m^2 and the greenhouse roof area of 400 m^2 were taken.

$$Q_s = \left[\frac{A_1}{R_1} + \frac{A_2}{R_2}\right](T_i - T_d) f_w f_c f_s \tag{1}$$

A_1: Greenhouse lateral area;
A_2: Greenhouse roof area;
R_1: Heat resistance of building material;
R_2: Heat resistance of building material;
T_i: Minimum greenhouse internal temperature value;
T_d: Outside temperature value;
f_w: Wind factor;
f_c: Structure factor;
f_s: System factor.

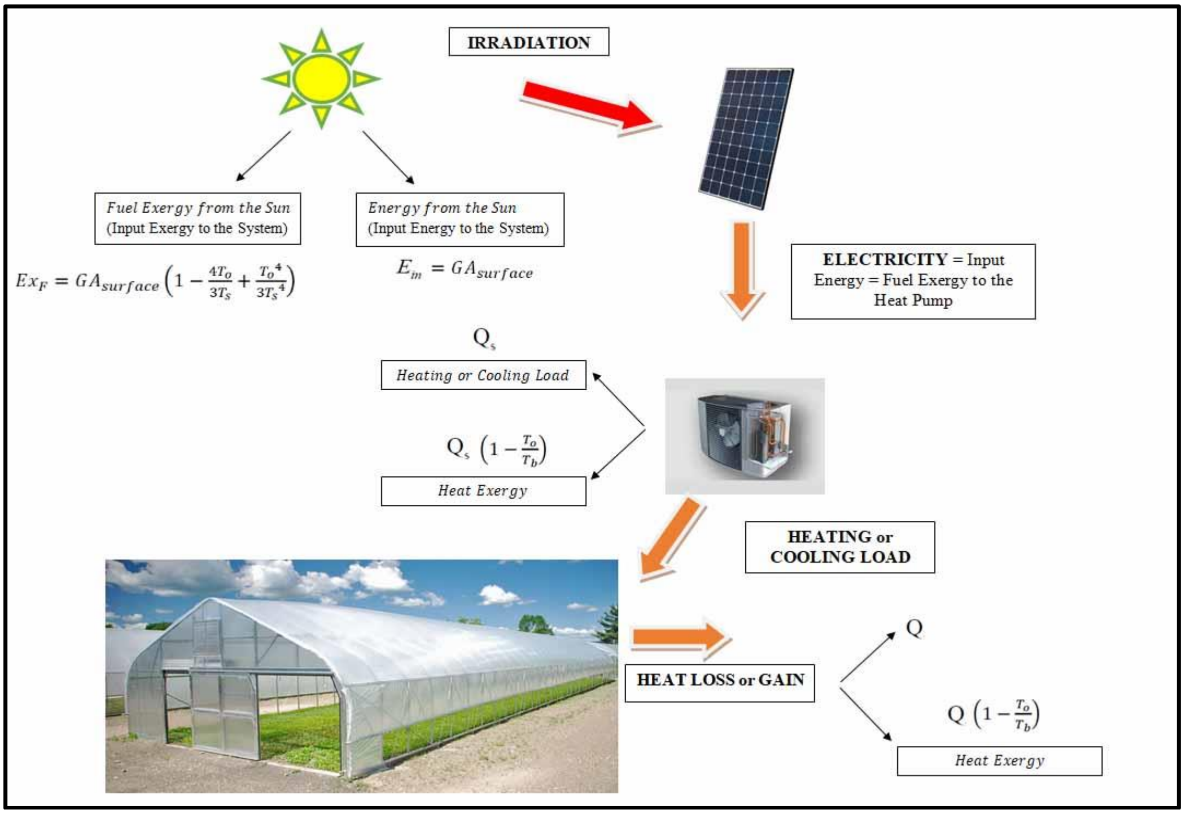

Figure 1. Energy and exergy transfer between greenhouse, energy source, and environment.

4. Analysis

The greenhouse described in Section 3 was analyzed via an exergetic approach.

Firstly, the energy analysis should be described. According to the first law of thermodynamics, the energy is not generated or consumed; just conserved. It can be written as:

$$\Delta E = E_{in} - E_{out} \tag{2}$$

where ΔE, E_{in}, and E_{out} are the energy change, energy input, and energy output. Here, the energy input or output can be work or heat. Considering the conventional approach, energy efficiency for any closed or open system is expressed as:

$$\eta = \frac{W}{E_{in}} \tag{3}$$

Secondly, exergy analysis is considered as follows:

$$\dot{E}x_{D,k} = \dot{E}x_{F,k} - \dot{E}x_{P,k} \tag{4}$$

Equation (4) is the exergy balance equation, and the terms of this equation are explained as follow:

Ex_F: Fuel exergy;
Ex_P: Product exergy;
Ex_D: Exergy rate destruction;
k: *k*th component.

Exergy is not conversed like energy, and some amount of the exergy is depleted, which is called the exergy destruction. Exergy destruction represents the irreversibilities or lost work potential that cannot be used again. Exergy may be described as the quality of the energy source used. The exergy efficiency represents the quality of energy. The most quality use of the energy occurs at the reversible process, and there is still a potential of energy use until the system reaches the environmental conditions. The exergy efficiency shows how a system closes the reversible one, and it is written as the following equation:

$$Ex_F = GA_{surface}\left(1 - \frac{4T_o}{3T_s} + \frac{{T_o}^4}{3{T_s}^4}\right) \tag{5}$$

where G is the total horizontal solar energy to the surface (kJ/m^2), Asurface is the surface area (m^2), and T_o and T_s are the environmental temperature and temperature of the sun (in K).

$$Ex_p = Q_s\left(1 - \frac{T_o}{T_b}\right)t \tag{6}$$

$$\eta = \frac{Ex_F}{Ex_P} \tag{7}$$

η_k: Exergy efficiency of the system

Two different indices are presented in Refs. [22-26], and the unavailability and exergy inefficiency are expressed in the following equations.

$$\gamma = \frac{Ex_D}{Ex_F} \tag{8}$$

$$\beta = \frac{Ex_D}{Ex_P} \tag{9}$$

The unavailability is the rate of exergy destruction to the fuel exergy, representing a depletion of the energy source. The exergy inefficiency is a rate of exergy destruction to the product exergy, which shows how much exergy is depleted per product. These indices might be used for the sustainability evaluations, although they measure the unsustainability, and it is a good result if they have low values.

5. Results and discussion

In this work, we explored a greenhouse heat demand met by a heat pump in the Afghanistan weather conditions. The greenhouse was kept at 20 ^{o}C, and the electricity required to run the heat pump was taken from the grid. Some exergetic aspects and some novel exergetic indices called unviability and exergy inefficiency were taken into account. The daily mean values were used for the calculations, and the weather condition values were taken from the TRNSYS 18 software. As it is well known, the heating process exists if the environmental temperature is lower than 20 ^{o}C, and vice versa is for the cooling process.

Figure 2 represents the temperature variation; according to the values, the maximum daily mean environment temperature was 34.14 ^{o}C, and the minimum one was -7.13 ^{o}C for Heart. In the calculations, the heating and cooling requirements were considered, and the electricity needed by the heat pump was calculated assuming that COP was 2.5.

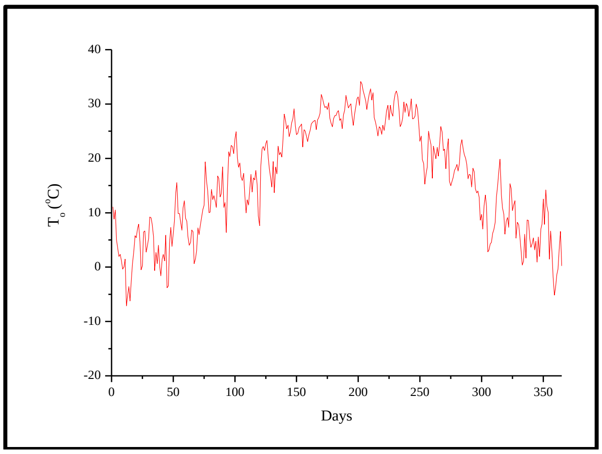

Figure 2. Change of mean daily temperature for Herat.

Figure 3 depicts the fuel exergy or electric energy required by the heat pump. It was assumed that the cooling period was between 15 April (105th day of the year) and 15 October (288th day of the year). One can see that the electricity required in the cooling period is much lower than the heating session's electricity. This event is the more critical daily temperature in the summer due to the differences. The maximum electricity input reaches 25.59 kWh, while the minimum electricity input is equal to 0.01 kWh.

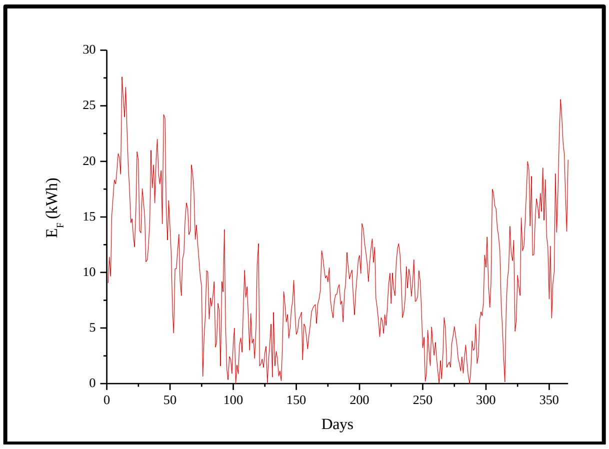

Figure 3. Change of fuel exergy/electricity input.

Figure 4 shows the product exergy, heat exergy input from the greenhouse for the heating season, and heat exergy output from the greenhouse for the cooling season. It can be seen that the trends of figures 3 and 4 are the same, resulting from the calculation methodology, in which the electricity needed is defined by multiplying the heating/cooling load by COP. Similar to the electricity need, the product exergy is higher for the heating season than the cooling season. The maximum product exergy is 6.38 kWh, while its minimum is zero.

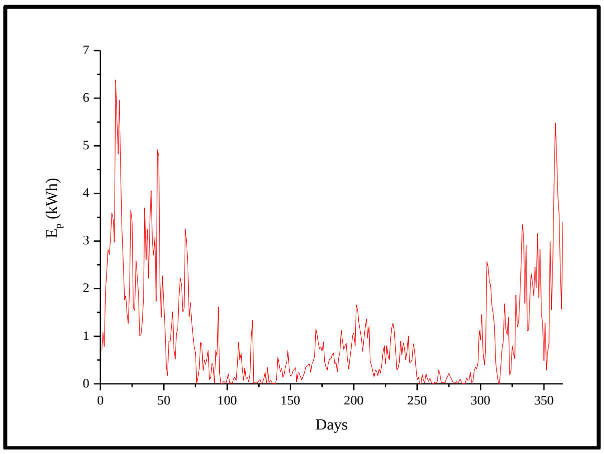

Figure 4. Change of product exergy.

The exergy destruction variation is shown in figure 5. Exergy destruction, as mentioned in Section 3, is the measure of irreversibilities; in other words, lost power potential in a system and the system cannot use this lost power. The exergy destruction value is a primary indicator for determining the irreversibility rate in the system, and causes inefficiencies. Figure 5 has very high values compared to the product exergy, which means that only a tiny portion of the electricity can be converted into a valuable product, and the other potion is consumed. According to the calculations, its maximum value reaches 21.21 kWh, equal to 77% of the maximum electricity input and 3.32 times more than the product exergy.

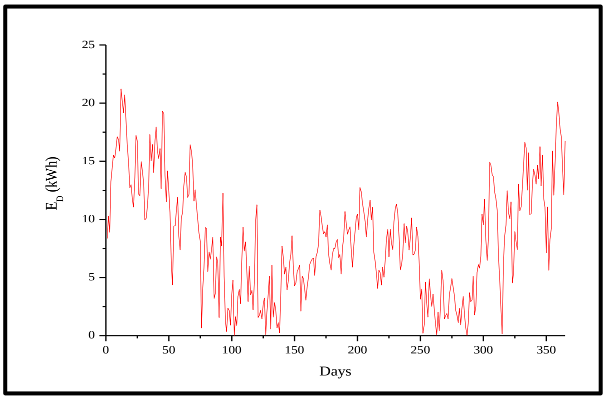

Figure 5. Change of fuel exergy/electricity input.

Figure 6 shows the changes in the exergy efficiency, which is a primary indicator for evaluating how quality energy is used. The exergy efficiency is different from the energy efficiency or COP for heat pumps. The energy efficiency is just about how much energy is used in order to obtain a useful product, while the exergy efficiency is about how quality energy is used to obtain a useful product. The exergy efficiency has variable values since it depends on the ambient temperature, although COP is assumed to be constant. The maximum exergy efficiency is 0.23, and the minimum one is zero. As it can be seen, it is very low compared to COP, and the reason for this inefficient use or no-quality use of the energy is the high exergy destruction.

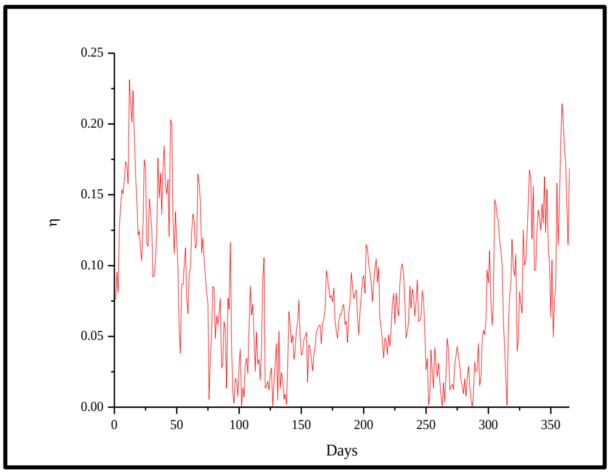

Figure 6. Change of fuel exergy efficiency.

Figures. 7 and 8 indicate the unavailability and exergy inefficiency indices for the heat pump systems. It is mentioned from the inefficient use of the energy in the previous paragraph, and these indicators help us determine the measure of the inefficiencies. The unavailability rate is the rate of the exergy destruction to the fuel exergy or electricity input. It shows how much work potential is depleted in the process. Similarly, the exergy inefficiency is the exergy destruction rate to the exergy product, which compares the exergy product and the exergy destruction. In other words, the unavailability shows how much energy source is depleted, and the exergy inefficiency shows how much potential work is destroyed per product exergy. These are very useful for evaluating the systems' sustainability by calculating how inefficient the system is. The results obtained show that both of these indicators have undesired values, i.e. very high; they are desired to be low values as the indicators of unsustainability.

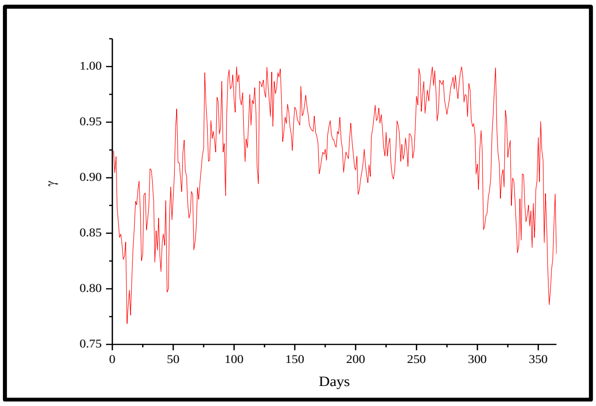

Figure 7. Change of unavailability.

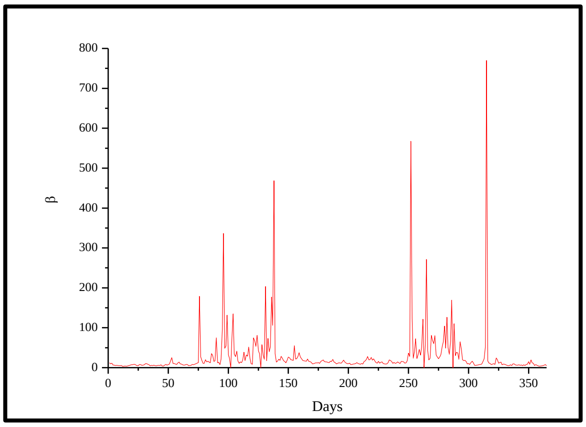

Figure 8. Change of exergy inefficiency.

This work is about a greenhouse in Afghanistan, in which a heat pump meets the heating and cooling loads. Firstly, a basic exergetic analysis shows that the heat pump is very inefficient in using the energy source quality, although it has a COP 2.5. After determining that the heat pump is inefficient, a measure of this inefficiency is calculated using the unavailability and exergy inefficiency indices suggested in Refs. [35-39]. The results obtained show that both of these indices are so high, and using heat pumps for the greenhouse heating/cooling operations is not unavailable for Herat since the indicators show that the energy source is depleted insufficiently, and most of the source is depleted per unit product exergy. Avoiding this unsustainable use of heat pumps, some solutions can be found as follow:

-Instead of an air source heat pump, a ground source heat pump with a higher COP may be used as a heat pump.

-The renewable energy sources can generate electricity.

-on the on-site production/consumption is another alternative.

6. Conclusions

This work was about determining a heat pump's inefficiencies in sustainability/unsustainability, and an application was made for Herat in Afghanistan. Some essential conclusions are listed as follow:

-The exergy/electricity input reaches 25.59 kWh, while the minimum value is equal to 0.01 kWh.

-The maximum product exergy reaches 6.38 kWh.

-The maximum and minimum exergy efficiencies are 0.23 and zero, respectively.

-The unsustainability criteria are very high; the unavailability rate reaches 0.99 and the exergy inefficiency reaches 9380.

Finally, it is recommended that this system should undergo other research works in detail using other exergy or sustainability methods like exergoeconomic, exergoenvironmental, advanced exergy-based approaches, sustainability indicators, and thermo-ecological cost analysis.

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