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Second law of thermodynamics and heat pumps for domestic heating

K.Kaygusuz[1,a]

[1]Karadeniz Technical University, Faculty of Science, Trabzon, Turkey.

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Abstract
The release of energy can be used to provide heat when a fuel burns in a furnace, to produce mechanical work when a fuel burns in an engine, and to generate electrical work when a chemical reaction pumps electrons through a circuit. Thermodynamics, the study of the transformations of energy, enables us to discuss all these matters quantitatively and to make useful predictions. The recognition of two classes of process, spontaneous and non-spontaneous, is summarized by the Second Law of thermodynamics. This law may be expressed in a variety of equivalent ways. One statement was formulated by Kelvin: no process is possible in which the sole result is the absorption of heat from a reservoir and its complete conversion into work. In recently, extensive studies have been conducted on heat pumps for refrigeration and air conditioning of the buildings and automobiles. The objective of this study was to investigate the second law of thermodynamics and heating performance characteristics of the heat pump, especially solar assisted heat pumps for domestic heating.

Keywords: Second law of thermodynamics; heat engines; heat pumps; solar energy.

1. Introduction

The first law of thermodynamics concentrates on the conservation of energy (the experimental observation that energy can be neither created nor destroyed) and shows how the principle of the conservation of energy can be used to assess the energy changes that accompany physical and chemical processes. The release of energy can be used to provide heat when a fuel burns in a furnace, to produce mechanical work when a fuel burns in an engine, and to generate electrical work when a chemical reaction pumps electrons through a circuit. In chemistry, we encounter reactions that can be harnessed to provide heat and work, reactions that liberate energy which is squandered but which give products we require, and reactions that constitute the processes of life. Thermodynamics, the study of the transformations of energy, enables us to discuss all these matters quantitatively and to make useful predictions [1-3].

Some things happen naturally; some things don't. A gas expands to fill the available volume, a hot body cools to the temperature of its surroundings, and a chemical reaction runs in one direction rather than another. Some aspect of the world determines the spontaneous direction of change, the direction of change that does not require work to be done to bring it about. A gas can be confined to a smaller volume, an object can be cooled by using a refrigerator, and some reactions can be driven in reverse. However, none of these processes is spontaneous; each one must be brought about by doing work [1]. Thermodynamics is silent on the rate at which a spontaneous change in fact occurs, and some spontaneous processes may be so slow that the tendency is never realized in practice whereas others are almost instantaneous. The recognition of two classes of process, spontaneous and non-spontaneous, is summarized by the Second Law of thermodynamics. This law may be expressed in a variety of equivalent ways. One statement was formulated by Kelvin: *"No process is possible in which the sole result is the absorption of heat from a reservoir and its complete conversion into work"* [1].

Heat pumps have a tremendous potential to bring renewable heating into houses. Because heat pumps are electricity-driven, there is a direct interaction with other energy demands within the built environment, such as PV panels. By using heat pumps in a flexible way, it is possible to better integrate these different electricity producing and consuming devices. This helps the energy supply to

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[a] Corresponding author;
Phone: +90-+90-462-377-2591, Email: kamikk@ktu.edu.tr

be more reliable, with a higher share of renewable input. On the other hand, the combination of a heat pump and solar energy system would appear to alleviate many of the disadvantages that each has when operating separately. During winter, the energy that could be collected by the solar system, but that would be too low in temperature to be useful for direct heating, may be used as a source for the heat pump. Because the solar collector storage system can supply energy at temperatures higher than the ambient outdoor air, the capacity and COP of the heat pump would increase over those for the heat pump alone, the peak auxiliary load requirement would be reduced, and the combined heating system would seem to operate more economically. The operation of the solar system at temperatures near or below room temperature would decrease the collector losses and allow more energy to be collected. The lower collection temperature might allow the use of collectors with one or no covers, and this would reduce the first cost from a conventional two-cover solar system. Finally, for those areas where warm temperatures occur during cloudy periods, the combined system might compensate for the reduced performance of the conventional solar system under cloudy conditions and the low capacity of the heat pump in cold weather [5-15].

Extensive studies have been conducted on heat pumps for refrigeration and air conditioning of the buildings and automobiles. However, studies of the performance characteristics of the coolant source heat pump using wasted heat of electric devices for an electric bus in heating mode are rare. The objective of this study was to investigate the second law of thermodynamics and heating performance characteristics of the heat pump, especially solar assisted heat pumps for domestic heating.

2. First and Second Laws of Thermodynamics

2.1. Introduction

In the first law of thermodynamics, or the conservation of energy principle, to processes involving closed systems. Energy is a conserved property, and no process is known to have taken place in violation of the first law of thermodynamics. Therefore, it is reasonable to conclude that a process must satisfy the first law to occur. However, as explained below, satisfying the first law alone does not ensure that the process will actually take place. It is common experience that a cup of hot coffee left in a cooler room eventually cools off [4].

This process satisfies the first law of thermodynamics since the amount of energy lost by the coffee is equal to the amount gained by the surrounding air. Now let us consider the reverse process-the hot coffee getting even hotter in a cooler room as a result of heat transfer from the room air. We all know that this process never takes place. Yet, doing so would not violate the first law as long as the amount of energy lost by the air is equal to the amount gained by the coffee [1-4].

It is clear from the above that processes proceed in a certain direction and not in the reverse direction. The first law places no restriction on the direction of a process, but satisfying the first law does not ensure that that process will actually occur. This inadequacy of the first law to identify whether a process can take place is remedied by introducing another general principle, the second law of thermodynamics. We show later in Part III that the reverse processes discussed above violate the second law of thermodynamics. This violation is easily detected with the help of a property, called *entropy*, defined in the next part. A process will not occur unless it satisfies both the first and the second laws of thermodynamics. The second law has been stated in several ways as [4]:

- ***The principle of Thomson (Lord Kelvin) states:*** *"It is impossible by a cyclic process to take heat from a reservoir and to convert it into work without simultaneously transferring heat from a hot to a cold reservoir"*. This statement of the second law is related to equilibrium, i.e. work can be obtained from a system only when the system is not already at equilibrium. If a system is at equilibrium, no spontaneous process occurs and no work is produced. Evidently, Kelvin's principle indicates that the spontaneous process is the heat flow from a higher to a lower temperature, and that only from such a spontaneous process can work be obtained.
- ***The principle of Clausius states:*** *"It is impossible to devise an engine which, working in a cycle, shall produce no effect other than the transfer of heat from a colder to a hotter body"*. A good example of this principle is the operation of a refrigerator.

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- ***The principle of Planck states:*** *"It is impossible to construct an engine which, working in a complete cycle, will produce no effect other than raising of a weight and the cooling of a heat reservoir".*
- ***The Kelvin-Planck principle*** may be obtained by combining the principles of Kelvin and of Planck into one equivalent statement as the Kelvin-Planck statement of the second law. It states: *"No process is possible whose sole result is the absorption of heat from a reservoir and the conversion of this heat into work".*

The second law is not a deduction from the first law but a separate law of nature, referring to an aspect of nature different from that contemplated by the first law. The first law denies the possibility of creating or destroying energy, whereas the second law denies the possibility of utilizing energy in a particular way. The continuous operation of a machine that creates its own energy and thus violates the first law is called perpetual motion of the first kind. A cyclic device which would continuously absorb heat from a single reservoir and convert that heat completely to mechanical work is called a perpetual-motion machine of the second kind. Such a machine would not violate the principle of conservation of energy, since it would not create energy, but economically it would be just as valuable as if it did so. Hence, the second law is sometimes stated as follows [4]: *"A perpetual motion machine of the second kind is impossible".*

2.2. Thermal energy reservoir

In the development of the second law of thermodynamics, it is very convenient to have a hypothetical body with a relatively large thermal energy capacity that can supply or absorb finite amounts of heat without undergoing any change in temperature. Such a body is called a thermal energy reservoir, or just a reservoir. In practice, large bodies of water such as oceans, lakes, and rivers as well as the atmospheric air can be modeled accurately as thermal energy reservoirs because of their large thermal energy storage capabilities or thermal masses [4].

A body does not actually have to be very large to be considered a reservoir. Any physical body whose thermal energy capacity is large relative to the amount of energy it supplies or absorbs can be modeled as one. The air in a room, for example, can be treated as a reservoir in the analysis of the heat dissipation from a TV set in the room, since the amount of heat transfer from the TV set to the room air is not large enough to have a noticeable effect on the room air temperature. On the other hand, a reservoir that supplies energy in the form of heat is called a source, and one that absorbs energy in the form of heat is called a sink. Thermal energy reservoirs are often referred to as heat reservoirs since they supply or absorb energy in the form of heat [2-4].

2.3. Heat engines

Work can easily be converted to other forms of energy, but converting other forms of energy to work is not that easy. The mechanical work done by a propeller placed in a bucket of water, for example, is first converted to the internal energy of the water. This energy may then leave the water as heat. We know from experience that any attempt to reverse this process will fail. That is, transferring heat to the water will not cause the shaft to rotate. From this and other observations, we conclude that work can be converted to heat directly and completely, but converting heat to work requires the use of some special devices. These devices are called heat engines. Heat engines differ considerably from one another, but all can be characterized by the following [4]:

- They receive heat from a high-temperature source (such as solar energy).
- They convert part of this heat to work (usually in the form of a rotating shaft).
- They reject the remaining waste heat to a low-temperature sink (the atmosphere).
- They operate on a cycle

Heat engines and other cyclic devices usually involve a fluid to and from which heat is transferred while undergoing a cycle. This fluid is called the working fluid. The term heat engine is often used in a broader sense to include work producing devices that do not operate in a thermodynamic cycle. Engines that involve internal combustion such as gas turbines and car engines fall into this category. These devices operate in a mechanical cycle but not in a thermodynamic cycle since the working fluid does not undergo a complete cycle. Instead of being cooled to the initial temperature, the exhaust gases are purged and replaced by fresh air-and-fuel mixture at the end of the cycle. Figure 1 shows a schematic view of the heat engine.

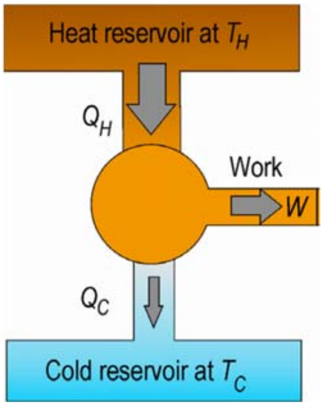

Figure 1. A simple schematic overview of the heat engine.

3. The Second Law of Thermodynamics and Heat Pumps

3.1. Introduction

No heat engine can convert all the heat it receives to useful work. This limitation on the thermal efficiency of heat engines forms the basis for the Kelvin-Planck statement of the second law of thermodynamics, which is expressed as follows [1-4]:

- It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.
- The Kelvin-Planck statement can also be expressed as follows: No heat engine can have a thermal efficiency of 100 percent, or for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.

It is important to note that the impossibility of having a 100 percent efficient heat engine is not due to friction or other dissipative effects. It is a limitation that applies to both the idealized and the actual heat engines.

We all know from experience that heat flows in the direction of decreasing temperature, i.e., from high-temperature mediums to low temperature ones. This heat transfer process occurs in nature without requiring any devices. The reverse process, however, cannot occur by itself. The transfer of heat from a low-temperature medium to a high-temperature one requires special devices called refrigerators. The objective of a heat pump is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low-temperature source, such as well water or cold outside air in winter, and supplying this heat to the high-temperature medium such as a house. An ordinary refrigerator that is placed in the window of a house with its door open to the cold outside air in winter will function as a heat pump since it will try to cool the outside by absorbing heat from it and rejecting this heat into the house through the coils behind it. Figure 2 shows the heat pump cycle.

The measure of performance of a heat pump is also expressed in terms of the coefficient of performance COP_{HP}, defined as [4]:

$$COP_{HP}=\frac{Q_H}{Q_H - Q_L} \tag{1}$$

$$COP_{HP} = COP_R + 1 \tag{2}$$

The relation implies that the coefficient of performance of a heat pump is always greater than unity since COP_R is a positive quantity. That is, a heat pump will function, at worst, as a resistance heater, supplying as much energy to the house as it consumes. In reality, however, part of Q_H is lost to the outside air through piping and other devices, and COP_{HP} may drop below unity when the outside air temperature is too low. When this happens, the system usually switches to a resistance heating mode.

Most heat pumps in operation today have seasonally averaged COP of 2 to 3.

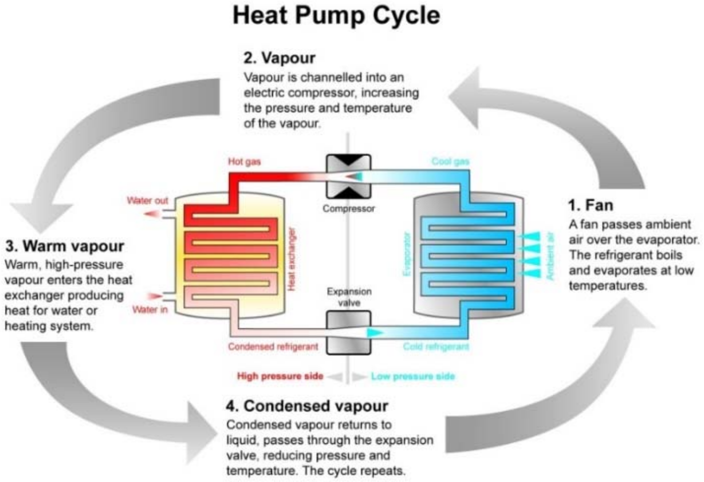

Figure 2. A schematic presentation for heat pump cycle.

3.2. Performance of solar assisted heat pump system

Research and development in the solar-assisted heat pump (SAHP) field has been concerned with two basic types of systems: direct and indirect. In direct systems, refrigerant evaporator tubes are embodied in a solar collector, usually of the flat plate type. Research has shown that when the collector has no glass cover plates, the same collector surface can also function to extract heat from the outdoor air. The same surface may then be employed as a condenser, using outdoor air as a heat sink for cooling [5-15].

3.2.1. Parallel System

As shown in Figure 3, the parallel system consists of a solar collector, a water-to-air heat exchanger, an air-sourced heat pump, a water-circulating pump, a storage tank, and other equipment. The parallel SAHP system is combining two main components: the solar system and the parallel heat pump system. In this system, the heat pump uses ambient air as an energy source while the water-to-air heat exchanger uses solar energy as a heat source, and they give their energies to the load one by one. Solar energy is used to meet as much of the heating requirement as possible. Thus, the total available energy of the system is the sum of the extracted energies from two different systems (solar and the heat pump system) [10-14].

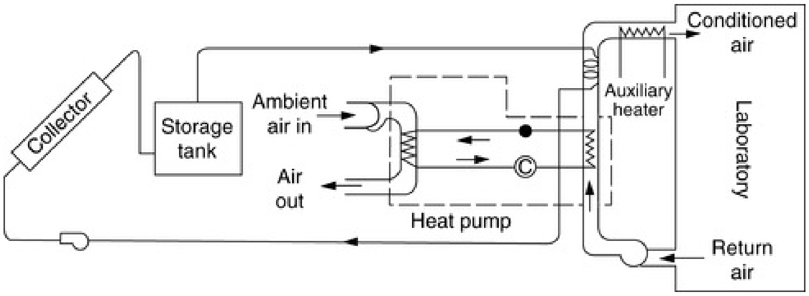

Figure 3. Parallel heat pump system.

3.2.2. Series system

Figure 4 shows a series system. The solar collector heats water, which is then stored in a tank. The tank provides heat directly to the house if the tank temperature is above 40°C, and the heat pump draws heat from the tank when the tank temperature is between 5 and 40°C. This system has the advantage that the tank can be operated at lower temperatures when required, allowing the collector to operate with high efficiency, and the tank heat storage capacity can be increased by the amount of sensible heat stored between 5 and 40°C. The disadvantage of the system is that when the tank temperature finally drops to 5°C, the heat pump cannot be used further without danger of freeze-up in the water tank. The system shown will not provide air conditioning because there is no way in which to exhaust the waste heat to outside air. It would be possible to provide air conditioning if there were another heat exchanger loop between the storage tank and outside air, but this would add to the cost of the heat exchanger and its associated circulating pump. A development effort is required on the heat pump in this system because residential heat pumps are not currently designed to operate efficiently with evaporator temperatures above 20°C, and this one would have to operate at up to 40°C.

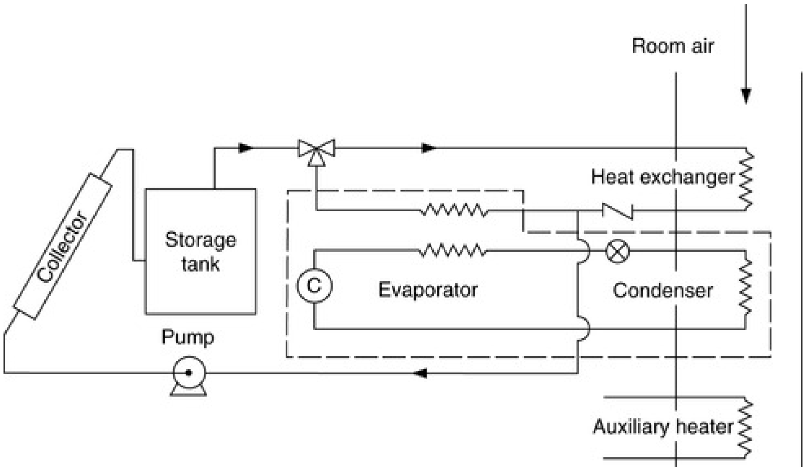

Figure 4. Series heat pump system.

3.2.3. Dual-Source System

The dual-source SAHP system, illustrated in Figure 5, combines the advantages of the parallel and series systems and overcomes their disadvantages. The solar collector, heat storage, and building heat exchanger all continue to work as a simple solar system so long as the tank temperature remains above 40°C. At temperatures below that, the heat pump system is called on by a microprocessor controller, and a decision is made as to whether it is better to draw the heat pump's heat from the tank or from the outside air. The control strategy options are numerous for this system; it can be operated to optimize savings of electricity or to reduce peak loads. It would be the most efficient of all the systems described here. It has the disadvantage that the required heat pump is complex and will be costly to manufacture. Considerable development work will be required to ensure that the unit can be operated in all sequences of its modes with full reliability. With this system, air conditioning is accomplished by operating the unit as a simple air-to-air heat pump in the cooling mode, using only the outside heat exchanger as a condenser. So, it is obvious that the dual-source heat pump system takes advantage of the best features of the series and parallel heat pump systems. The system is not capable of using the storage tank to reduce air-conditioning peak loads during the summer because the heat pump cannot be used to cool the tank to the outside air [10-14].

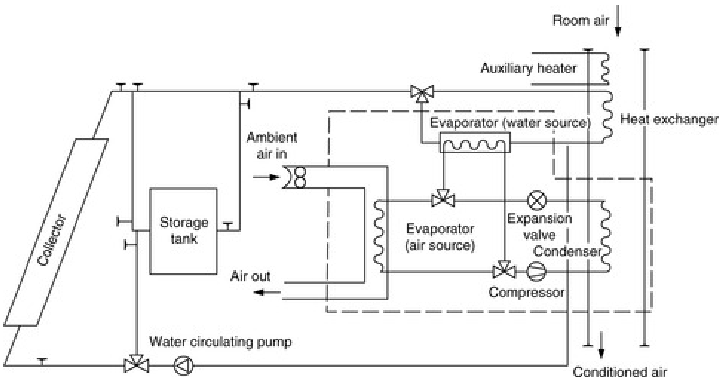

Figure 5. Dual-source system.

3.2.4. Method of theoretical analysis

The complexity of the thermal analysis of solar-assisted heat-pump systems makes the use of computer simulations the only feasible method for determining the system dynamics and performance. These simulations were performed with the simulation program SOLSIM [6]. This was modified to include the heat-pump system performance behavior as indicated by the experimental set-up. So, this computer program contains some subroutines, which model the behaviors of individual pieces of hardware (i.e. collectors, storage tanks, heat pumps, building heating load), and an executive routine which links these component models and solves the resulting system of equations. The simulation calculations are performed with a 30 min computational time step to allow consideration of the transient effects and short-term interactions of components [10-14].

The heat-pump model used in these simulations is quasi steady-state in nature. The heat pump has two heat sources for the evaporator: these are the water and air sources. The actual performance data obtained from experimental results are used to generate third-order polynomials relating the heat pump's COP to the source temperature. For the dual-source heat pump, two different sets of polynomials are used, one set relating to the water source and the other for the air source.

For the water-source heat pump:

$$COP = 5.46 + 5.33 \text{ x } 10^{-2}T_w - 5.53 \text{ x } 10^{-4}T_w^2 + 1.20 \text{ x } 10^{-6}T_w^3 \quad (3)$$

$$Q_{con} = 21.42 - 5.62 \text{ x } 10^{-2}T_w - 7.47 \text{ x } 10^{-4}T_w^2 + 2.63 \text{ x } 10^{-6}T_w^3 \quad (4)$$

For the air-source heat pump:

$$COP = -27.86 + 0.121T_a + 1.601\text{x}10^{-4}T_a^2 - 7.035\text{x}10^{-7}T_a^3 \quad (5)$$

$$Q_{con} = 18.45 - 0.101T_a + 6.508 \text{ x } 10\text{-}5T_a^2 - 5.044 \text{ x}10^{-7}T_a^3 \quad (6)$$

The solar system modeled is a conventional liquid-medium system. The collector parameters include F_R, b, $(\tau\alpha)_{eff}$ and $I_{s,ref}$. Insolation was chosen as a repeating, sinusoidally varying function, and, in this case, the time of sunrise, day length and peak insolation were specified. The heating load was specified as constant, given at each time. The storage capacity was specified and the storage was chosen as stratified according to the experimental results. Heat losses from the store are accounted for by specifying the overall thermal loss coefficient. The ambient temperature is modeled as a daily sinusoidal variation around an average ambient temperature. The SOLSIM required inputs are given in Table 1 and 2.

Table 1. SOLSIM required inputs

Specific heat capacity of working fluid (J/kg.ºC)	**4183**
Length of simulation (min)	900
Calculation interval (min)	15
Collector aperture area (m^2)	30
Value of $(\tau\alpha)_{eff}$	0.80
Value of *a*	0.0
Value of *b*	1.0
Value of F_R	0.9
Water mass flow rate at collectors (kg/min)	21.6
Value of $I_{s,ref}$ used in *b* (W/m^2)	800
Building heating load (J/h)	$1.8\text{x}10^7$
Water mass flow rate at load side (kg/min)	21.6
Thermal capacity of storage (J/K)	$2.6\text{x}10^8$
Initial temperature (K)	293
Minimum temperature to load (K)	293
Maximum allowed storage temperature (K)	312
Storage tank overall loss coefficient (W/m^2.ºC)	0.250
Storage tank *L/D* ratio	2.46
Stratified latent heat storage (number of temperature layer)	3
Treated as sinusoidal around ambient average (K)	281
With a positive maximum swing (K)	12
Is a simple sine curve to be used ?	Yes
Maximum solar radiation (W/m^2)	800
Day length (sunrise-sunset) (min)	600
Time of sunrise (h)	07:00

Table 2. Solar assisted series heat pump system parameters for SOLSIM

Properties of solar collectors	
Number of glass covers	1
Thickness of glass cover	0.004 m
Refractive index	1.45
Collector plate absorptance	0.90
Collector emittance	0.85
Collector efficiency factor	0.85
Black and side losses	1.20 kJ/h.m^2.K
Mass flow rate	40 kg/h.m^2
Total collector area	30 m^2
Number of collectors	18
Heat pump information	
Capacity	5820 W
Compressor type	Hermetic
Evaporator type	Water-cooled shell and tube
Condenser type	Air-cooled copper tube
Evaporating temperature	7.2 ºC
Condensing temperature	54.4 ºC
Air mass flow rate in condenser	2420 m^3/h

4. Results and discussions

The function, *F*, is shown in Figure 6, for Trabzon, as a function of collector area for the conventional heat pump, conventional solar system, and series, parallel and dual source heat-pump systems. For a building with neither a conventional solar-energy system nor a heat pump system, F equals zero. For a building (in our simulations, the laboratory building with a 75 m^2 floor area) with only a conventional (air-to-air) heat pump, the fraction of the heating requirement supplied by free energy (non-purchased) is q_{air} divided by the total heating requirement of the building and equals 50%. Since the air-to-air heat pump does not contribute to the heating load, the value of F depends on the COP and the relative size of the space to be heated and building heating loads during the heating season. In the case of a conventional solar system, *F* depends on the collector area and the storage mass; as the collector area and storage mass increase, *F* increases.

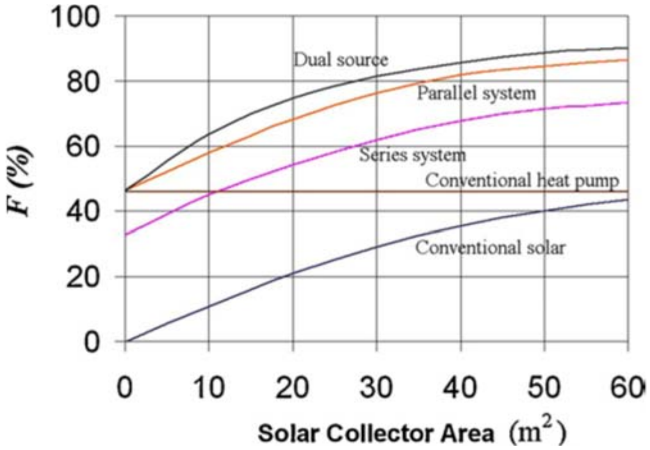

Figure 6. Fraction of the load met by free energy as a function of the solar collector area.

The F curves for the conventional solar systems are in agreement with results predicted by the *f*-chart method [7-9] to within a few percent as shown in Figure 6 for Trabzon over the heating season. The collector size necessary for the solar-energy system to consume less auxiliary energy than the conventional heat-pump system is between 20 and 30 m^2 for a climate like Trabzon.

The simulation results show that the seasonal performance of the collector for the solar-assisted parallel heat pump and conventional solar systems of the same collector area are equal. In the case of solar-assisted series and dual-source heat-pump systems, the collector performances of the same collector area are not equal. Clearly, the improved collection efficiency is the direct result of the solar-assisted heat-pump capability, which maintains lower average storage temperatures and hence lower collector temperatures in the series system. Figure 7 shows the collector efficiencies for single-cover solar-assisted series and dual-source systems and for single-cover conventional solar and parallel heat-pump systems over the heating season.

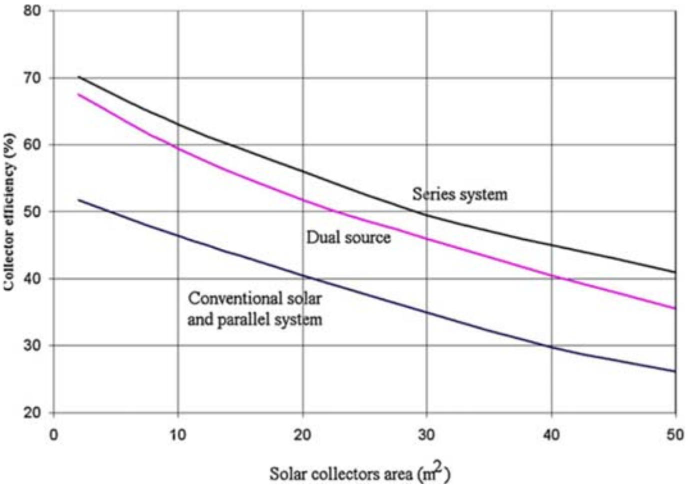

Figure 7. Solar collector efficiency as a function of collector area.

The seasonal energy balance requires that the sum of all the energies supplied equals the heating load of the building, or:

$$q_{solar} + q_{air} + W_{hp} - q_{aux} = Q_L \quad (7)$$

The relative contributions from each of these four heat sources is shown in the bar graphs of Figure 7 for the parallel, series and dual-source heat pump systems and for the conventional solar and heat-pump systems. The combined height of the q_{solar} and q_{air} bars in Figure 6 and 7 represents the percentage of the total heating requirement supplied by free energy and is therefore equal to the *F* value.

As shown in Figure 8 and 9, adding the solar-energy capability to the conventional solar system to create the series system increases q_{solar} modestly. The balance of the heating load must be supplied by purchased energy (W_{hp} and q_{aux}) because q_{air} is equal to zero for both systems. The net increase in *F* is q_{sol}/q_{load}.

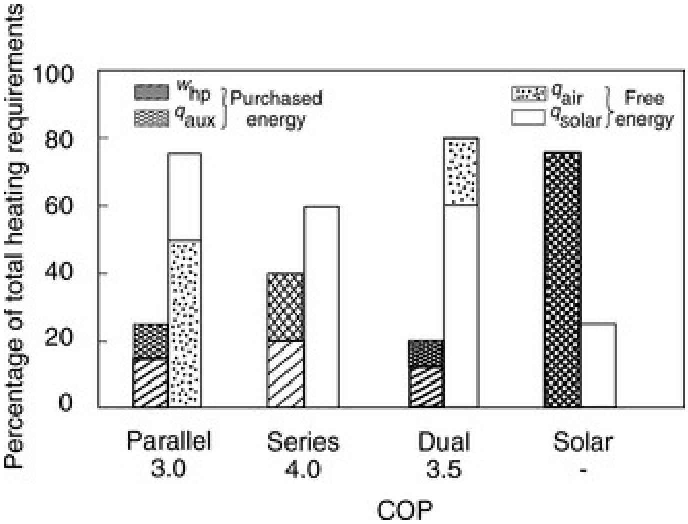

Figure 8. Heating contributions from all possible sources for Trabzon, Turkey

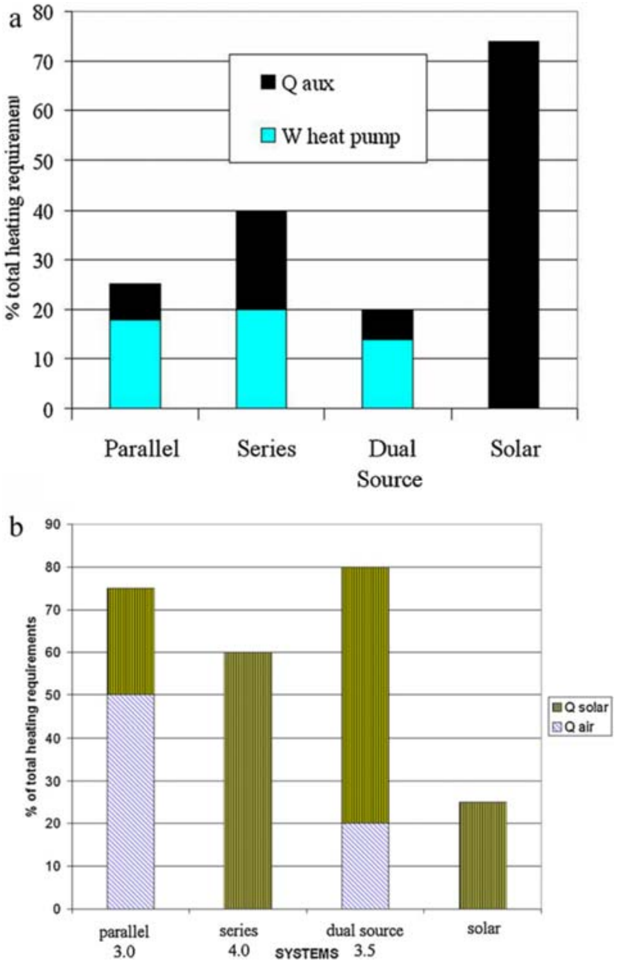

Figure 9. (a and b) Fraction of the total heating requirement to purchased energy and free energy [15].

The heat-pump's seasonal COP varies between the systems. The use of a solar source for the heat pump raises the seasonal COP over that of the conventional and parallel heat-pump systems.

As shown in Figure 8 and 9, the seasonal heat-pump heating COPs for the parallel, dual source and series heat-pump systems are 3.0, 3.5 and 4.0 respectively. As expected, the COP for the series and dual source heat pumps are substantially higher since they utilize the stored solar energy. Table 3 shows theoretical performance of the solar-assisted parallel heat pump system for heating season. Table 4 also shows the theoretical performance of the solar-assisted series heat pump system for heating season.

Table 3. Theoretical performance of the solar-assisted parallel heat pump system for heating season

Months	Number of working days of the SAPHPS	Heat Pump COP	Average outdoor Air temp. (^oC)	Solar Radiation (MJ/m^2.day)	Collector Efficiency (%)	Storage Efficiency (%)	Percent of heating load supplied by the SAPHPS (%)
November	30	2.94	14.4	6.24	52	56	80
December	30	2.92	10.2	4.74	54	58	76
January	30	2.82	6.6	5.12	55	62	50
February	28	2.72	5.2	8.06	50	60	40
March	30	2.86	7.2	6.94	54	64	76
April	30	3.00	11.6	11.84	56	66	86
May	12	3.14	15.8	16.62	62	68	92

SAPHPS: Solar Assisted Parallel Heat Pump System

Table 4. The theoretical performance of the solar-assisted series heat pump system for heating season

Months	Number of working days of the SASHPS	Heat Pump COP	Average outdoor Air temp. (^{o}C)	Solar Radiation (MJ/m^2.day)	Collector Efficiency (%)	Storage Efficiency (%)	Percent of Heating load Supplied by the SASHPS (%)
November	21	4.44	14.4	6.24	62	62	62
December	14	4.34	10.2	4.74	62	64	46
January	16	4.30	6.6	5.12	64	66	50
February	20	4.24	5.2	8.06	66	66	52
March	22	4.34	7.2	6.94	68	68	66
April	24	4.60	11.6	11.84	70	68	72
May	10	4.80	15.8	16.62	68	67	82

SASHPS: Solar Assisted Series Heat Pump System ; COP: Coefficient of performance for heat pump

5. Conclusions

The author analyzed the performance of solar assisted heat pump with energy storage for residential heating by using SOLSIM computer simulation program. In the theoretical study, over the heating season, the mean value of COP, the number of operating days per month, the percentage of building heating load met by the solar assisted systems, the average collector and storage efficiencies of the parallel and series heat pump systems have been deduce from obtained data and given in Table 3 and 4. The following conclusions were obtained:

- The nature and performance of a dual source heat pump system must be carefully considered when a building is heated by a heat pump combined with solar collectors. The addition of solar collectors can result in lower costs attributed to the ground thermal probes, as it may be possible to reduce the length of probe required.
- It is also important to take into account pumping costs within the primary energy analysis, as increased pumping costs may reduce the financial advantages of a dual source system, particularly in mild climates.
- Solar and heat pump systems is a combined technology that can take a market share in the segment of building heating and cooling since it carries some advantages: high renewable energy share, lower electricity demand, lower primary energy demand, lower CO_2 emission depending on the electricity mix feeding the heat pump. Market share of solar heat pump systems could reach 100 % of new houses in many countries where heat pump technology is well implanted and solar is mandatory for domestic hot water.

Combining solar and heat pump technologies is relevant in several aspects: a high renewable fraction can be achieved and the safety of the solution makes it a good choice for many homeowners. The solar heat can help enhance the performance of the heat pump by raising the evaporation temperature. And the solar heat can be stored at low temperatures (0-80 °C) thus making good use of the collectors even during the cloudy days or at night. It is possible use of the latent heat of 2.0 m^3 of $CaCl_2.6H_2O$ melted/solidified around 32 ^{o}C for heating applications.

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