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Impact of the Heat Pump on the Environment

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Abstract

The paper deals with the impact of a mechanical compression heat pump, operated by electrical energy, on the environment. Irrespective of its origin and the history of its production, this energy pollutes the environment as waste heat. The operational energy, obtained from the so-called alternative energy sources (wind, water energy), also burdens the environment as waste heat. This is not the case with the solar energy. A direct conversion of the Sun's rays into electricity does not additionally affect the environment, compared to their direct conversion into heat without our intervention.

Keywords

Heat Pump, Environment

1. Introduction

1.1. Environment

The space of the Earth and its atmosphere, corresponding to the upper layer of the lithosphere and the lower layer of the atmosphere constitutes our natural environment. This environment is permanently exposed to various destructive invasions which change its original properties. Several philosophers have been motivated to take action against the invasions with the goal of protecting the environment [1]. For example, more than a century ago, in 1874, George Perkins Marsh (1801-1882) published a book about man's destruction of the environment [2]. On page 33, after the heading *Destructiveness of Man*, Marsh writes:

Man has too long forgotten that the earth was given to him for usufruct alone, not for consumption, still less for profligate waste.

Similar ideas about the protection of the environment have been expressed by other scientists. Nikola Tesla (1856-1943), for example, in 1900, considered the exploitation of natural fuel resources as an irreversible invasion of our living system [3]. He was apparently the first to oppose the production of motive power by consumption of matter, particularly against the production of electricity by burning coal [3], p. 16, right column:

…to burn coal, however efficiently, would be a mere makeshift, a phase in the evolution toward something much more perfect. After all, in generating electricity in this manner, we should be destroying material, and this would be a barbarous process.

In the same paper, Tesla analyzed several novel far-reaching ideas on obtaining driving power from alternative energy sources, such as wind energy, hydropower, solar power, geothermal energy and direct conversion of Sunrays into electricity, see also [4]. Nikola Tesla's ideas are gradually being realized, but his name is rarely, if ever, mentioned in the literature in this context.

1.2. Heat Pump

A heat pump is an energy consumption machine that is mostly used to heat or cool a certain space. Its main components are two heat reservoirs with different temperatures, an expansion valve, and a compressor for vapour of working substance. The compressor takes the vapour from the lower temperature reservoir and brings it up to the temperature of the hotter reservoir. The process is equivalent to pumping heat from a lower to a higher temperature. The energy required for this non-spontaneous heat transfer process is provided by an external electrical energy source. The compressor transforms it in mechanical energy and supplies to the working substance. In the end, this increases the quality of the transported heat.

Figure 1 compares the central units of a mechanical water pump and a heat pump [5]. The water pump increases the pressure of the fluid while its temperature remains largely unchanged. The heat pump transports the working substance, the heat carrier, in a vapour state. Due to the compression of vapour, its pressure and temperature rise simultaneously in the compressor. The heat carrier is transported against a higher temperature. Hence, somewhat misleading, the name heat pump is derived. Taking heat as the kinetic energy of the smallest parts of matter, it is not the heat that is being compressed and pumped, but rather its carrier.

1.3. Objectives of the Work

The intention of this paper is to shed some more light on the interaction of the heat pump with the environment. We identify the environment to be any substance (liquid, solid, gas) that can absorb, store and release heat. For simplicity, we assume that only one heat pump acts on the environment. For the same reason, the energy source required to operate the pump shall not be a part of the environment. The mechanical compression heat pump, adopted for the consideration, is operated by electrical energy.

The model shows that the environment receives all the electrical energy required for the operation of the pump as waste heat. By this we ignore the possible energy losses accompanying the production of electrical energy and assume a steady—states heat pump operation process.

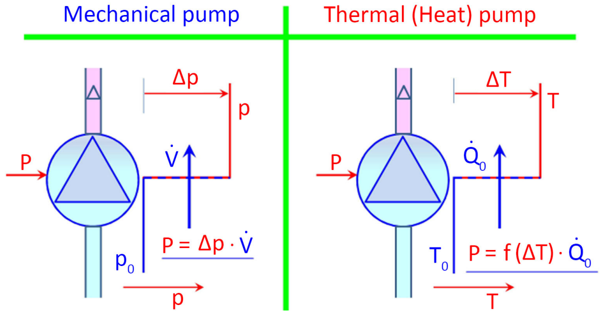

Figure 1. Pressure change (left) in a water pump and temperature change (right) in the heat pump, taken from [5]. $\dot{V}$ is the water flow rate, Δp is the pressure difference due to the water pump, P is the power of the pump (compressor), ΔT is the temperature difference due to vapour compression, and $\dot{Q}_0$ the heat flow rate that the working substance takes from the reservoir of lower temperature.

2. Energy Flows in the Heat Pump

2.1. Flow Diagram of the Pump

Figure 2 shows the flow diagram of a typical heat pump installation. This installation is adopted in the present paper and used as a model to heat a building. The air, soil and groundwater on the left constitute the lower, the building on the right the higher temperature reservoir. The wide green-red arrow represents thermal energy (heat) $\dot{Q}_0$ taken from the environment. The heat is transferred as an ordinary flow to the heat sink (building), by the working fluid that circulates in the installation. The thin yellow arrow indicates the high-quality (electrical) energy L_t required to operate the pump. The two flows combine in the compressor, forming the energy flow $\dot{Q}$ which enters the building to be heated. To simplify the discussion, they are represented here by separate arrows.

2.2. Interaction Heat Pump-Environment

To illustrate the fate of energy flows in the heat pump installation, we consider the flow of energy (heat), the heat pump takes from the environment, separately from the energy it receives from an external source and uses for operating the installation. The separation of the two energy flows makes the model more transparent.

1) Energy taken from the environment

The considered building is embedded in the environment, and the energy required for evaporation of the working substance is taken from the environment, Figure 2, lower part. The vapour thus produced transports this energy to the heat pump's condenser, which is connected to the building. Here the vapour condenses and the heat released spreads throughout the building, raising its internal temperature.

2) Energy given off to the environment

Due to the imperfect thermal insulation of the building from the environment, the heat brought into the building diffuses through the elements of its boundary: walls, windows, etc. This flow of energy, called heat loss, escapes to the environment. In the operation of the heat pump, the environment receives the heat losses of the building, while at the same time provides heat necessary for evaporation of the working substance in the heat pump evaporator. This schema corresponds to common practice.

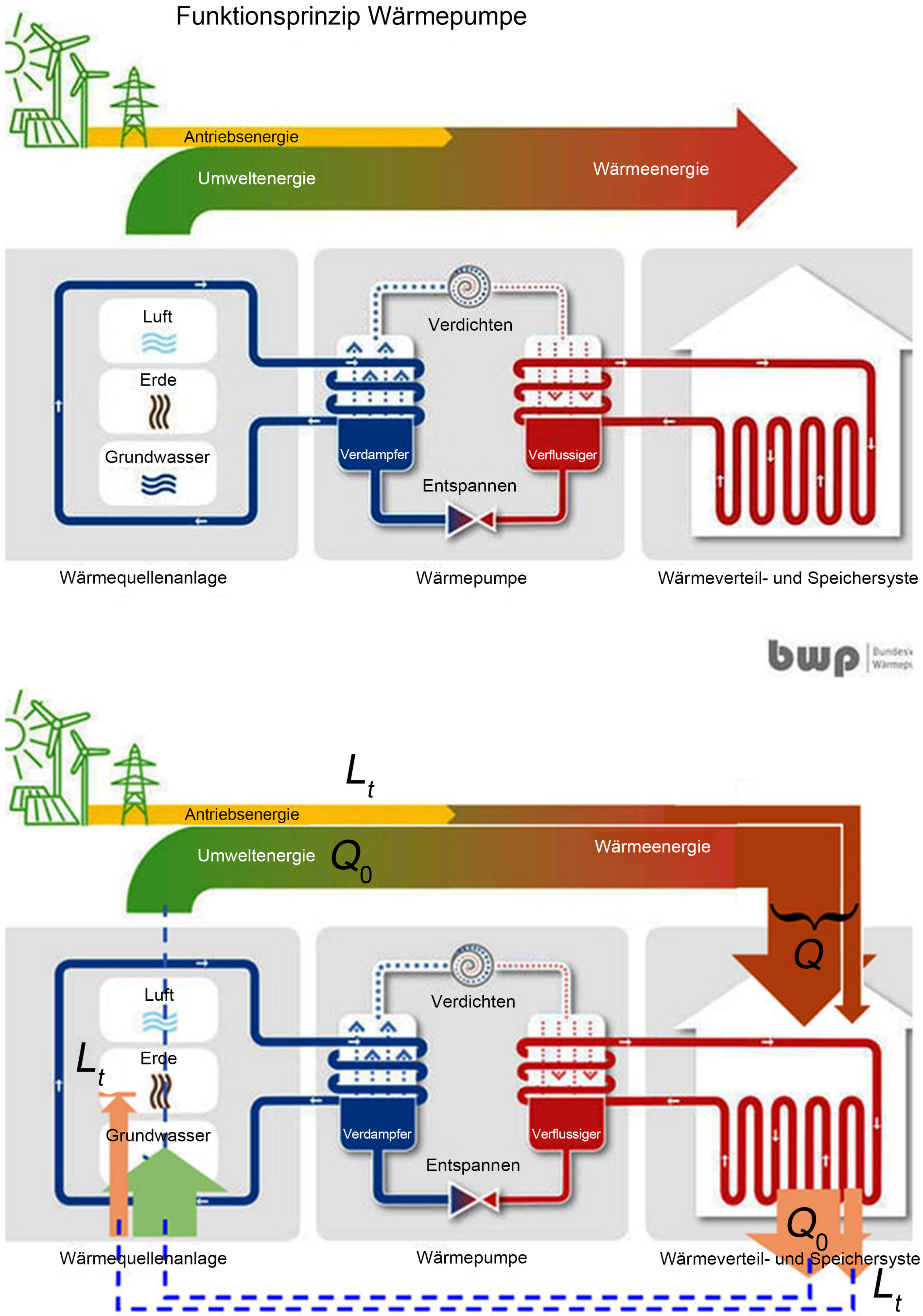

Figure 2. Flow diagram of the heat pump in operation. Upper diagram: The original bwp—drawing; lower diagram: expansion by the author of this work for easier discussion. bwp: Bundesverband Wärmepumpe—German *Heat Pump* Association, Source of the original: Startseite | Bundesverband Wärmepumpe (BWP) eV (waermepumpe.de).

3) Consequences

According to the model, the evaporator is the heat sink for the environment and simultaneously the heat source for the heat pump. The building acts as the heat sink for the heat pump, but as the heat source for the environment. In steady-state operation, the quantities of the heat $\dot{Q}_0$ at the input in, and the output from, the environment are equal. In other words, the heat $\dot{Q}_0$ is supplied to the environment at one position, but removed again at the other position. Since the input and output are sufficiently apart, nearly equal are also the temperatures of the heat carrier at their positions. Consequently, a simple heat balance shows that, in a steady-state operation, the heat $\dot{Q}_0$—on average—does not affect the environment temperature. The model fulfils the requirement of a cyclic process, namely the sum of all thermal effects of the cycle must be zero.

4) Energy received from the external source

The energy used for operating the heat pump, L_t, is obtained from an external source, **Figure 2**, above left corner. This energy also enters the building and the environment as part of the overall energy flow, but its fate is different from that of the energy $\dot{Q}$ taken from, and returned back to, the environment. The operating energy does not perform a closed cyclic process as an organized energy flow, but only a one-way process, the path of which extends from its external source to the environment, where it becomes absorbed and vanishes through diffusion. Consequently, it ends up in the environment and affects its temperature. Its flow resembles the flow of a river that disappears into a sandy desert.

In conclusion, the considerations show that only the energy L_t taken from an external source and used to operate the heat pump affects the environment thermally.

2.3. Energy Balances

The above discussion is now casted into energy balances for the building and the environment. Again, first only one heat pump is interacting with the environment. In a steady state operation, the energy supplied to the building diffuses as heat loss $\dot{Q}_{LOSS}$ into the environment. The energy $\dot{Q}_0$ taken from the environment is used in the evaporator for evaporation of the working substance. The quantities needed for the balances are shown in **Figure 2**, lower part.

The total energy flow rate supplied to the building, $\dot{Q}$, leaves the building as heat loss $\dot{Q}_{LOSS}$ hence,

$$\dot{Q} = \dot{Q}_0 + L_t = \dot{Q}_{LOSS}. \tag{1}$$

The environment absorbs the energy, $\dot{Q}_{LOSS}$, and, at the same time, supplies to the evaporator of the heat pump the energy $\dot{Q}_0$. Denoting the energy that remains in the environment by $\dot{Q}_{EN}$ we get:

$$\dot{Q}_{EN} = \dot{Q}_{LOSS} - \dot{Q}_0 = \dot{Q}_0 + L_t - \dot{Q}_0 = L_t. \tag{2}$$

Equation (2) expresses the heat balance of the environment. As it shows, the energy required for the operation of the heat pump L_t remains in the environment as wasted energy that increases its temperature. Consequently, the environment is sink of the energy operating the heat pump.

If multiple heat pumps interact with the environment simultaneously, but independently from each other, their total environmental impact $\dot{Q}_{ENT}$ is equal to the sum of the individual impacts,

$$\dot{Q}_{ENT} = \sum_k L_{tk} , \quad (3)$$

where the index *k* refers to the *k-th* heat pump.

3. Origin of the Operating Energy

The electrical energy, L_t, for the heat pump operation can be generated by converting several forms of energy stored in various carriers: air (wind, wind farms), water (waterfall, water waves), solids (coal, wood), earth (hot rock), solar energy. With the exception of deep geothermal energy, all other forms of energy are related to solar radiation, presently or in the far past. When creating driving energy from energy stored in air and water, we mostly convert high-quality mechanical energy into heat, which ends up as waste in the environment. In the case of solid substances as energy carriers, energy is extracted as heat by burning the carrier (coal, wood) or by cooling the carrier in a process that requires working energy. By burning the energy carrier, all combustion products (solids, gases, heat) end up in the environment as waste and affect its properties, such as constitution and temperature. In the case of deep geothermal energy, we convert high temperature heat into lower temperature heat and further into other forms of energy. They all perform a process of energy degradation and end up in the environment as waste.

Several authors have dealt with the energy degradation and dispersion in various conversion processes. Of these, I mention only two pioneers in this field of physics, namely, James Watt (1736-1819) [5] and William Thomson (Lord Kelvin, 1824-1907) [6].

Consequences of energy degradation. Any energy conversion that generates heat as the main or as by-product (waste) increases the temperature of the environment. The opposite process is only heat radiation from the Earth's surface into the space. If the radiation process does not compensate for the wasted heat, an increase of the environment temperature, accompanied by the evaporation of water from the Earth's surface and the formation of vapour clouds in the atmosphere might be expected. Clouds shield the Earth from the space and reduce the heat radiated from its surface. This increases the evaporation of water on the Earth's surface and supports the autocatalytic process that raises the temperature on the Earth's surface. The so-called renewable energy works in the same way, because this energy is not used to restore the energy that was previously disappeared into the environment as waste. What is renewed is not the energy, but only the cycle of its generation.

Solar radiation absorbed by the Earth is converted into heat without any action on our part. Therefore, the solar radiation can be converted into other forms of energy without additional burden on the environment. For these reasons, solar energy shall be preferably used as a source of driving energy.

The biggest impact of the heat pump on the environment is expected if the production of the working energy includes the combustion of energy carrier. Consequently, a complete impact analysis should take into account all energy conversion steps which cover the production of raw materials to the final product (electricity), taking into account also the production of all elements of the heat pump itself.

4. Conclusions

The suitability of a heat pump as an energy transformer for heating depends crucially on the roots and production of its working energy. If these roots lie in the energy carrier and if the extraction of the energy from the carrier does not involve a chemical reaction, the environment is mostly thermally polluted in the production process. The mere disposal of driving energy as waste into the environment is also only of a thermal nature. In the event that chemical reactions are required, the environment is polluted with all reaction products. This is also the case with the so-called regenerative energy sources.

Only the solar energy as a source of energy does not burden the environment more than it does without our intervention. If electricity is considered as source of driving energy, regardless of its history, then the heat pump affects the environment only as the thermal equivalent of the electricity used to operate the pump. However, such an analysis would be incomplete; what is more important are the losses that accompany the energy transformation towards the production of electricity.

The operating energy of heat pump degraded to heat increases the ambient temperature and decreases heat losses from heated buildings. This can be viewed as a positive effect. However, this effect cannot in any way offset the damage caused by higher ambient temperatures.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

Origin of the heat pump

The roots of the heat pump lie in thermal process engineering. In 1853, the Austrian engineer Peter Ritter von Rittingen (1811-1872) [7] investigated the thickening of aqueous salt solutions by evaporating the solvent from the solution. He recognized that the emitted vapour took the latent heat of vaporization as a loss, **Figure A1**, left. To reduce this loss, he raised the vapour to a higher temperature with the help of a compressor and passed it through a heating pipe in the evaporator, **Figure A1** right. In this way, he was able to use the latent heat of vapour condensation to further heat the solution and evaporate its solvent. Today, this process is at the heart of every compression heat pump.

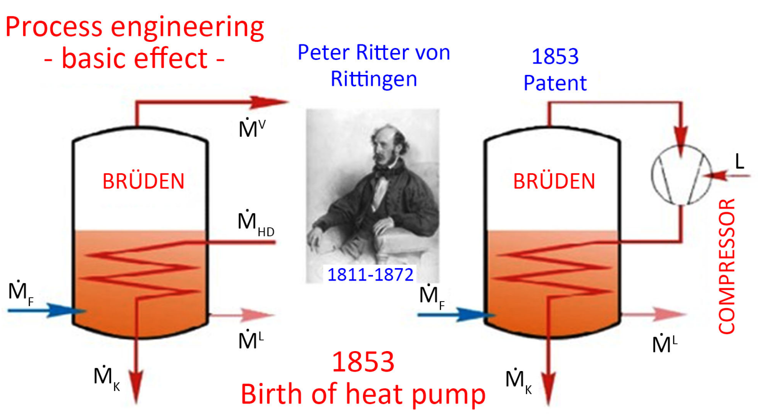

Figure A1. Evaporation of an aqueous salt solution without (left) and with compression and condensation (right) of steam. The process on the right resembles a heat pump.