

HEAT PUMPS FOR SPACE HEATING

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Summary

Heat pumps are devices extracting heat from a low temperature region and rejecting it into a higher temperature region. They consume energy (typically, in the form of mechanical work) to increase the temperature difference between two heat reservoirs, fighting the thermodynamic tendency for equalization of their temperatures. This chapter deals with the operational principles of heat pumps as well as with the different types that have been manufactured according to the market needs. The advantages and drawbacks of certain techniques and controls that have been implemented to reverse the operation in order to provide either heating or cooling effects in the same room are also examined.

1. General Principles

1.1 Background

The first theoretical information about heat pumps for room heating was given by *William Thomson* (later, lord Kelvin) in 1852. In several papers on this subject, he pointed out that motive power was obtained from “degrading heat” e.g. burning fuel, and the heat thereby

rejected was unavailable for further motive power recovery. William Thomson predicted that there will come a time when all fuel sources would be exhausted and thus motive power would no longer be available. Therefore, he designed a machine, which he called “Heat Multiplier”. It comprised a compressor and two water tanks serving as a hot reservoir and a cold reservoir. This arrangement would be capable of heating a room to a temperature higher than the ambient temperature by using less fuel than if such fuel was burned directly in the heater. Despite many attempts to exploit this idea, it remained unrealized for many years.

In the 1880s, the refrigeration technology emerged through the implementation of the vapor compression cycle on ammonia. The first two heat pumps were constructed by *J.G.N Haldane* in 1928 in Britain who intended to use them in his own house. A larger commercial machine was constructed by *J.A. Sumner* in 1946. In the late 1940s, low-capacity heat pumps appeared for heating purposes in individual houses. Due to the enthusiastic work of *Miss M. Griffiths*, a study was conducted in order to reveal possible heat pump applications initially in Britain. The research focused on the study of the simple reversed vapor compression cycle. A series of experiments were made to establish the Coefficients of Energy Performance related to sources like soil, air and water. In 1952, a heat pump was designed and constructed for London’s Festival Hall. Unfortunately, it was not successful due to design errors: it seems that the high standard of sound-proofing insulation of the building and the heat emitted by the occupants were not taken into account.

After 1950, the design of the heat pumps and their control systems were vastly improved and heat pumps started again to be used in many applications, especially in countries with moderate climate where they were expected to show higher efficiency. Despite the economical advantages of the heat pump systems at the time, technical weaknesses which arose during their operation decreased the faith of the first consumers towards them. During 1963-1972, a new recession in manufacturing and use of such devices was experienced, however researchers and engineers continued to improve their technical and quality features. The major challenges which emerged during the energy crisis in 1973 mainly in the industrialized countries caused careful revision of such devices as heat pumps. Today, heat pumps are air conditioning or simple cooling devices with a wide range of industrial as well as residential and office building applications.

In the United States, the usage of heat pumps for space heating was more effective due to the prevailing climatic conditions. Later, heat pumps were used in air conditioners for cooling purposes during the summer. Until the early 1980s, approximately 850,000 heat pumps were installed. In the mid 1980s, a high demand for small heat pumps grew in the United States and many European countries such as Norway, Sweden, Germany, France and Italy.

1.2 Principle of Operation of a Heat Pump

In a way, heat pumps operate similarly to common pumps (e.g. a water pump). When moving a mass of water from a lower to a higher level by consuming a certain quantity of energy (mechanical or electrical) offered by a pump, the energy balance is given by the equation:

$$\dot{W} = \dot{m}g\Delta h + \dot{m}gH_L \quad (1)$$

where:

\dot{W} : the rate of work offered by the motor

$\dot{m}g\Delta h$: is the rate of useful energy gained by the system

$\dot{m}gH_L$: is the rate of energy losses

According to the second law of thermodynamics, heat is naturally transferred from a body of higher temperature to a body of lower temperature and never the other way around, unless some other effect takes place. Moving heat towards the opposite direction is only possible through consumption of some form of energy, e.g. electrical energy, supplied by a motor. By using electricity and a vapor compression cooling cycle, it is possible to transfer (to or from a certain area) energy quantity as heat equal to double or even triple the consumed electrical energy. This is due to the fact that the work, W , produced (by the compressor) is added to the transferred heat Q_1 :

$$Q_1 + W = Q_2 \quad (2)$$

Therefore, according to the above formula, a heat pump releases an energy quantity greater than the work consumed.

The principle of operation of the heat pump is based on the theoretical Carnot engine operated in the reverse direction. In order for the Carnot engine to operate, two heat reservoirs, i.e. one of low temperature (T_1) and one of high temperature (T_2), are required. During the operation of this engine, heat supplied at temperature (T_2) produces work and rejects heat at (T_1). In the ideal conditions of full reversibility and no heat losses, the efficiency of this cycle is given by the formula:

$$\eta = \frac{T_2 - T_1}{T_2} \quad (3)$$

The reverse operation of the above cycle represents the operation of the heat pump. The consumption of mechanical work produces cooling/heating power. The efficiency of the pump in ideal conditions, also referred as COP (Coefficient of Performance), which characterizes its quality as well, equals to the inverse of the coefficient η :

$$\text{COP} = \frac{T_2}{T_2 - T_1} \quad (4)$$

This special “efficiency” (Coefficient of Performance) typically varies between 2.5 and 3.5.

According to equation (4), the COP of a heat pump depends only on the temperatures of the two heat reservoirs. This property may be extended to non-ideal conditions as well, where the COP is given by the formula:

$$\text{COP} = \frac{Q_h}{Q_h - Q_c} \quad (5)$$

where Q_h is the creditable energy from the condenser while Q_c is the given energy to the evaporator

Equation (4) shows that the temperature of the source from which heat is removed, the temperature at which the heat is rejected and the work consumed are key factors affecting the efficiency. Thus, the smaller the difference between these two temperatures, the smaller the consumed work and, consequently, the higher the efficiency (COP) of the heat pump. Therefore, heat pumps are more economically advantageous in countries with moderate climates.

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Biographical Sketch

Mrs. Irene Koronaki is an associate of the Department of Building Applications. She is a Mechanical Engineer and obtained her PhD in the Thermal Section of the Mechanical Engineering department of the National Technical University of Athens. She has experience in the field of Energy Efficiency in the building sector, regarding both building shell and services. She has participated in several research EC programmes (THERMIE, JOULE, SAVE, CRAFT) during her collaboration with the University of Athens, Department of Physics, as also as a collaborator of CRES. She is a member of ASHRAE and a registered engineer (Technical Chamber of Greece).