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ENERGY RECOVERY USING A HEAT PUMP IN HEATING AND AIR-CONDITIONING SYSTEMS

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ABSTRACT

In this paper, theoretic review of a heat pump use and operation is given. Further, the possibilities of a heat pump use in heating and air-conditioning is analysed, specially considering the tourist and catering facilities. The economic and environment protecting effects of a heat pump use as an energy source (conditionally speaking) in the air-conditioning process is pointed out. It is shown that these effects make a heat pump use justifiably attractive. In the end is pointed at the complexity of microprocessor regulation system which enables the heating and cooling capacity balance, when heat pump is used for both heating and cooling simultaneously.

1. INTRODUCTION

The term *heat pump* generally considers apparatus in which heat is conducted from a lower-temperature heat container to a higher-temperature heat container and it is there usefully applied. Heat pump process is equivalent to a cooling machine process. But, while a cooling machine transfers heat from a chilled medium to a higher-temperature medium uselessly, heat pump realises a cooling cycle where medium which delivers heat is usefully chilled and medium which receives heat is purposely heated. The heat amount, transferred to a higher-temperature heat container, equals the sum of heat conducted from a lower-temperature heat container and external work used up for a "heat pumping". Though every cooling machine is essentially a heat pump, this term is usually used for cooling machines where the main goal is a heat source (heating capacity of a condenser), instead of cooling capacity of an evaporator.

Fig. 1 presents the global plant scheme with an air-water heat pump, and the process is shown in the T,s diagram (Fig. 2).

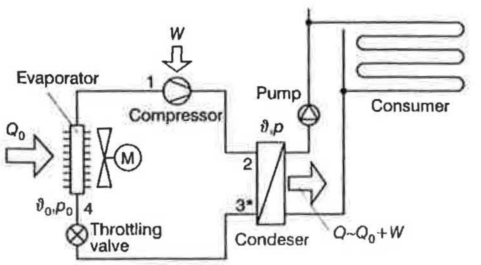


Figure 1.: Global plant scheme with an air-water heat pump

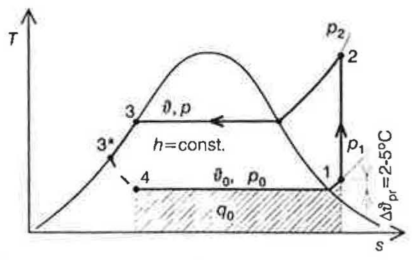


Figure 2.: Real heat pump process in T,s diagram

In real use, heat pump has a double task: it functions as a cooling energy source in summer period and as a heat energy source in winter period, or both simultaneously.

The real heat pump process performs according to Fig. 2 for achieving better efficiency and for compressor protection from hydraulic shock.

2. HEAT PUMP APPLICATION

High investment and exploitation costs of the air-conditioning plants give great possibilities for a heat pump use in energy recovery systems. All the year round heat pump use for heating and/or cooling is technically and economically justified, because during the summer period cooling energy can be produced, and during the winter period heat energy can be produced, so the whole air-conditioning system efficiency can be improved.

The energy recovery systems with heat pumps take advantage of the fact that in many modern buildings exist the interior rooms with negligible or none contact with the outside atmosphere. Since these rooms contain internal heat sources, such as the lighting fixtures, office machines, computers and employees, they can require all the year round cooling. In other words, they have a heat surplus even in winter period, so the cooling machine operation is needed, including a condenser heat energy use for heating of the exterior building rooms. Of course, this solution can be realised only when cooling loads of the interior rooms and heating loads of the exterior rooms in a building are in balance. When not, the solution should be technically improved, i.e. by building in the split condenser with or without a cooling tower for the purpose of an evaporator and condenser energy balance.

The factors for process goodness definition are the cooling multiplier $\varepsilon_C = q_o/(q_k - q_o)$ and the heating multiplier $\varepsilon_H = q_k/(q_k - q_o)$, where $\varepsilon_H > \varepsilon_C$. Two more coefficients characterise the heat pump performance: the coefficient of performance (COP) $\varepsilon = Q/W$, where Q is useful heat energy and W is used up work in the process and the seasonal performance factor (SPF) $\beta_j = Q_j/\Sigma W_j$, where Q_j is all the year round obtained heat energy and ΣW_j is used up high-worthy energy for running of the compressor, ventilator and/or pumps in the same period. Here should be also mentioned $\varphi = Q_{uj}/E_j$, called the heating coefficient in case of a heat pump or the cooling coefficient in case of a cooling machine, where Q_{uj} is useful heat energy and E_j is useful energy amount of a primary energy carrier, used up for running of the compressor, ventilator and/or pumps.

Generally speaking, heat pump use is recommended in buildings with a low-temperature heating systems (50°C/40°C), which are all the year round air-conditioned. On this occasion should be mentioned that, without an additional heat source, there exists the heat pump use limit in heating systems for the outside temperatures below approximately 0°C. Heat pumps are also often applied in buildings that require all the year round cooling for needs of a delicate technological processes and equipment.

Heat pumps today mostly use the R22 as refrigerant. Its substitution with R134 or R407, for the purpose of smaller influence on the environment, is, of course, possible with certain compressor reconstruction.

3. HEAT PUMP USE EXAMPLE IN AN INDOOR SWIMMING POOL

The example of a swimming pool will be used to describe the solution which uses, as the return heat of the process, the heat of condensation of cooling machine condenser in the indoor swimming pool air-conditioning process and pool water conditioning process as well. The cooling machine here is also the heat pump.

In indoor swimming pools, air-conditioning plant has to be able to take over steam which evaporates from the pool water surfaces, because of the wettability prevention on the cold surfaces of the building.

The indoor swimming pools operation requires a large quantity of energy,so the conditions for energy consumption optimalization should be created. It is achieved by the application of different energy recovery systems. The total energy consumption can be lowered up to 50% by building-in a recuperative heat exchanger or regenerator, and/or the heat pump. Using a recuperator and a heat pump, the energy recovery achieved in the process is equivalent to 100% of electrical energy used for compressor running. Such a solution, when the outside temperature is $J_0{}^3$-10°C, provides all the energy needed for the air-conditioning and the pool water heating, provided that the fresh air ratio in the process is approximately 20%. At higher temperatures of the outside air, the transmission energy losses are lowered, so the quantity of a total input energy is lower.

Figure 3. gives an example of an indoor swimming pool with an air-conditioning plant for all the year round monitoring and maintaining of temperature and relative humidity of the swimming pool room. It is achieved by using a recuperative heat exchanger and a heat pump for the processes of air and pool water treatment.

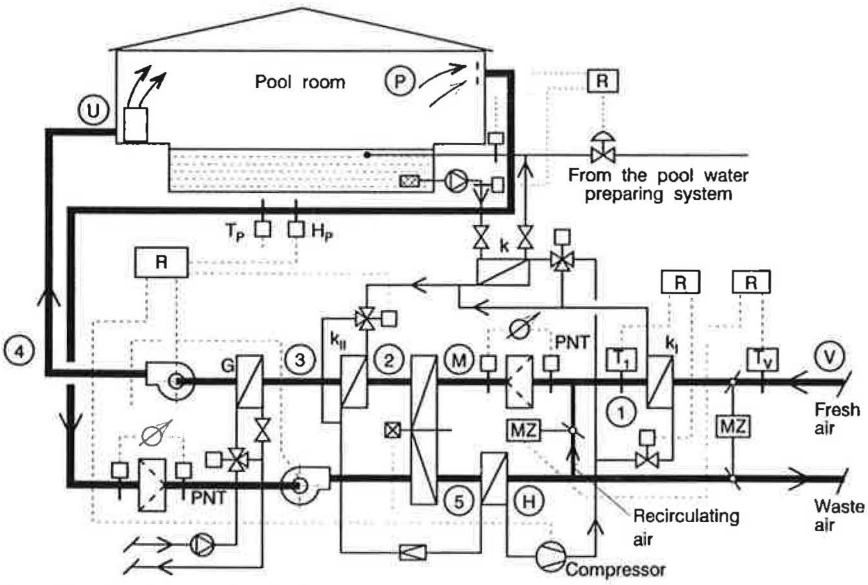


Figure 3. A scheme of an indoor swimming pool with an air-conditioning plant using a recuperator and a heat pump

3.1 Empty pool

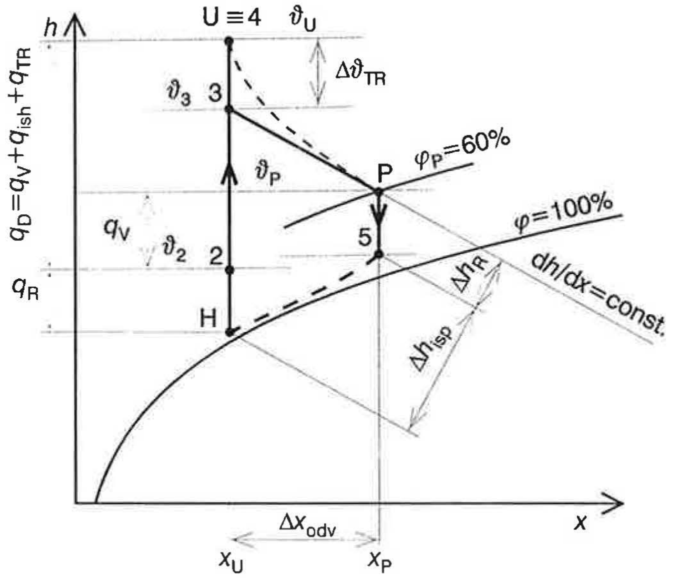


Figure 4. The process in h,x diagram-empty pool, 100% recirculating air, winter period

During the time the pool isn't used, the air-conditioning system supplies the delivery air of absolute humidity which enables dehumidification of the pool room. During that time, ventilators operate at minimum speed maintaining the particular thermodynamical air condition and the pool room ventilation, respecting the energy saving program. The return air from the pool room is supplied to the recuperative heat exchanger where sensible heat is carried away, and then the air is cooled on the evaporator for dehumidification. The automatic damper system is put in such a position that it enables a 100% recirculating air recovery into the process. The air is heated in the recuperative heat exchanger, and further heated on the condenser to the condition which can be given by the condenser capacity. Then the air is further heated on the heater to the condition of blowing in, which is determined by the room heat balance. If dehumidifying capacity in recirculating mode isn't sufficient, the automatic dampers of fresh, recirculating and waste air are modulated, and the pool room is dehumidified by certain air flows mixing ratio. If humidity of the pool room air decreases, the automatic dampers modulation is done reversely. The room temperature is controlled first by the control of a water heater capacity, and if temperature still increases, a part of cooling medium flow is automatically turned to the pool water heater. During the process, the full possible capacity of the waste air heat is used by means of a energy recovery system. In all the cases $\Delta h\text{R}=q\text{R}$ (Fig. 4).

3.2 POOL IN FULL CAPACITY - WINTER PERIOD

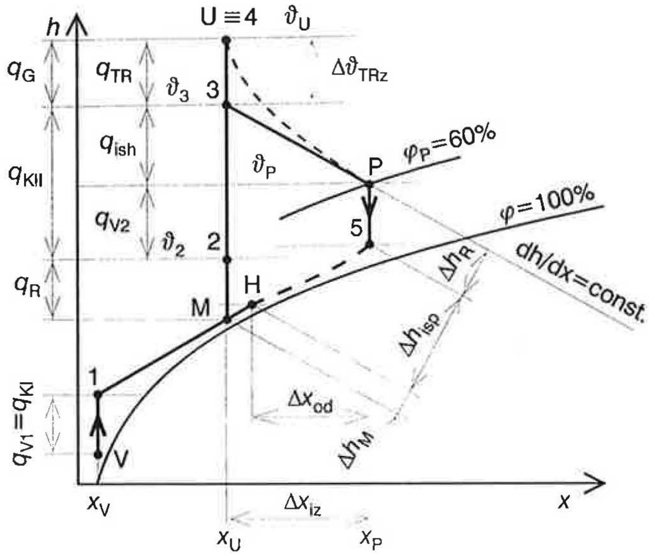


Figure 5. The process in h,x diagram-pool in full capacity, winter period

By this process (Fig. 5), the system works with full capacity. The process proceeds in the way that it has already been described, but the outside air, preheated on the first part of a heat pump condenser, is used. It enables that the air treatment process, at extremely low outside temperatures, proceeds to the left from the saturation boundary. The fresh air quantity is changed, in relation to the outside temperature, from minimum determined by microhygienic conditions, up to 100%. In that way, the outside atmosphere is used as a heat container and total energy consumption in the process is lowered. The fresh air is mixed with previously dehumidified recirculating air, it's heated again on the recuperative heat exchanger and further heated on the second part of the condenser. If it isn't sufficient, the fresh air is heated on warm water heater to the condition determined by the current room heat balance. In those periods when total heat of the heat pump condenser isn't used in the air-conditioning process, a part of cooling medium flow is turned, in order to secure heat balance of the process, to the heat exchanger (condenser k) where the pool water is heated.

The temperature of the air blowing-in in winter period is calculated using the following equation:

$$\vartheta_U = \vartheta_3 + \frac{Q_{sW}}{\rho \cdot c_p \cdot V_A} [°C] \qquad (1)$$

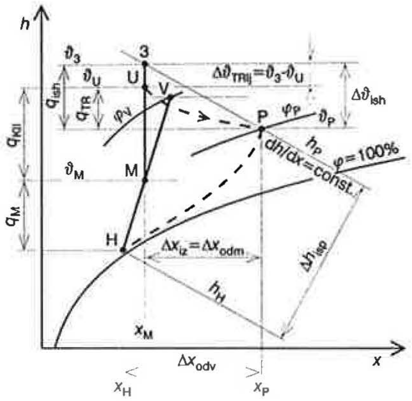
where Q_{sW} is total sensitive heat load in winter period.

3.3 POOL IN FULL CAPACITY - SUMMER PERIOD

In summer period there are two typical cases of air-conditioning system operating conditions, with respect to the outside air condition in relation to maintaining the desired pool room air condition:

1st case $J_V > J_P$ and $x_V < x_P$ (shown on Fig. 6)

2nd case $J_V > J_P$ and $x_V > x_P$ (shown on Fig. 7).



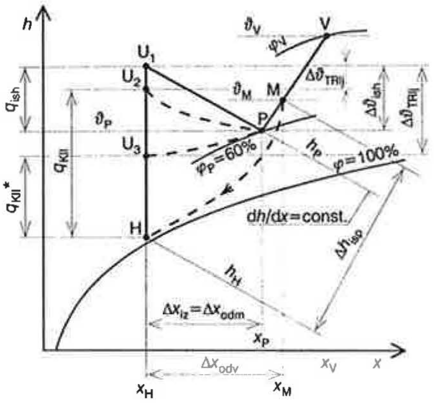


Figure 6. The process in h,x diagram-summer summer period with $J_V > J_P$ and $x_V < x_P$

Figure 7. The process in h,x diagram- period with $J_V > J_P$ and $x_V > x_P$

According to Fig. 7, as long as the outside temperature is higher then the pool room air temperature, the recuperative heat exchanger is out of service, the fresh air ratio in the process is minimum and it's determined by microhygienic requirements. After the mixing process of the fresh air flow and recirculating air flow, the air is chilled and dehumidified, and then heated again on the condenser k_{II} to the condition of blowing in which is determined by the current room heat balance.

In summer period, three typical processes should be distincted:

1. If $\Delta J_{ish} = \Delta J_{TRIj}$; $J_U > J_P$ the cooling process in the building is carried out completely at the expense of the evaporating process - the process is adiabatic.
2. If $\Delta J_{ish} > \Delta J_{TRIj}$; $J_U > J_P$ the cooling process in the building is carried out partially at the expense of the evaporating process - the process isn't adiabatic.
3. If $\Delta J_{ish} > \Delta J_{TRIj}$; $J_U > J_P$ the cooling process in the building is combined: cooling by
   evaporating + cooling by chilled air.

The temperature of the air blowing-in in summer period is calculated using the following equation:

$$\vartheta_U = \vartheta_3 - \frac{Q_{sS}}{\rho \cdot c_p \cdot V_A} [°C] \qquad (2)$$

where Q_{SS} is total sensitive heat load in summer period.

4. HEAT PUMP USE EXAMPLE IN A HOTEL FACILITY

Using the example of a hotel on the adriatic coast will be described the solution which uses the condensation heat of heat pump condenser in the hotel facility air-conditioning process and sanitary warm water preparing as well, and it also operates as the cooling machine. Now, instead of wasting the condensation heat in the atmosphere, it is used for the purpose of heating and/or it's stored in the system through the sanitary warm water.

The carried-out analysis of building's heat requirements has shown that in winter period, when the outside temperature is J_o¾°C, heat pump can completely cover building's heat losses. On the other side, heat pump in summer period, operating as a cooling machine, completely covers cooling energy requirements of the building and ensures required sanitary warm water quantity. When, in transitive period, there is a parallel requirement for heating and cooling capacity, their balance is solved by means of automatic microprocessor control, choosing the mediums flow direction.

Every heat pump in the system (Fig. 8.) includes compressor units, water-chilled shell & tube evaporator, water-chilled shell & tube condenser, air-chilled finned heat exchanger and automatic microprocessor control system. Evaporator and condenser may change roles, in relation to the operation mode. The finned heat exchanger can also operate as an evaporator or condenser, in relation to the process mode, so it enables the heat pump process balancing. In the process, using the condensation heat of heat pump condenser, sanitary warm water is preparing as well. By building in the accumulation tanks, the sanitary water heating is enabled in the night time, when low-cost electrical energy is consumed. The automatic microprocessor control of the system includes heating and cooling capacity control, antifreezing protection, part winding compressor start, medium parameters control for maintaining certain thermodynamical condition in the air-conditioned room, and the outlet temperatures regulation of warm and cold water. The automatic control is necessary in the heat pump process balancing.

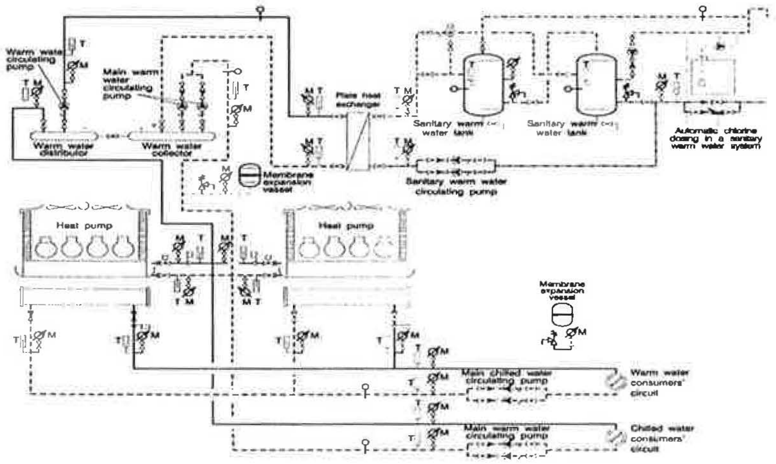


Figure 8. A scheme of an hotel air-conditioning plant using a heat pump

5. CONCLUSION

All the year round heat pump use is technically and economically justified, because heat pump can be used as a cooling energy source in summer period and as a heat energy source in winter period, or both simultaneously. All the year round heat pump use decreases initial investments (one heating/cooling unit) and it also decreases exploitation costs. Besides that, when heat pump is combined with energy recovery systems from waste air, significant energy savings are achieved.

Minor heat pump influence on the environment pollution, considering the electrical energy use as running energy source, makes such solutions, besides energetic and economic effects, also environment-friendly.

However, heat pump has the use limit below certain outside atmosphere temperature and also in building-in and application the noise protection must be carefully considered. Heat pump use in standard air-conditioning systems is also limited with condensing temperature relations (50°C/40°C). Air-conditioning plants with heat pump demand the use of highly-sophisticated automatic control systems for the purpose of energy balancing of the processes.

Considering the complexity of the problems, the authors point out a very interesting task to encourage the future scientific research on enlarging the problem to the all year round obtained and used up energy, in relation to the change of the outside atmosphere conditions.

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