Heat pumps – Efficient heating and cooling solution for buildings

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Abstract: In the actual economic and energetic juncture, the reduction of thermal energy consumption in buildings became a major, necessary and opportune problem, general significance. The heat pumps are alternative heating installations more energy-efficient and unless pollutant if we make a comparison with classic plants (liquid or gas fuel thermal boiler). This paper presents the necessity to use heat pumps in buildings' heating-cooling systems, energy and economic indices of performance, a new underground water heat pump system using a heat exchanger with special construction, tested in laboratory and the possibility to obtain the better energy efficiency with combined heating and cooling by heat pumps. Also, a case study presents the solution for heating a living building with a water-to-water heat pump, energy and economic advantages of this system.

Key-Words: Building heating/cooling, Renewable energy sources, Heat pumps, Heat pump performances, "Geoterm" system, Energy and economic analysis.

1 Introduction

Buildings are an important part of European culture and heritage, and they play an important role in the energy policy of Europe. Studies have shown that saving energy is the most cost effective method to reduce green house gas emissions (GHG). It has also pointed out that buildings represent the biggest and most cost effective potential for energy savings. The reduction of 26% energy use is set as a goal for buildings by the year 2020 which corresponds to 11% of the reduction of total energy use in European Union (EU) countries.

The buildings sector is the largest user of energy and CO_2 emitter in the EU, and is responsible for more than 40% of the EU's total final energy use and CO_2 emissions. At present heat use is responsible for almost 80% of the energy demand in houses and utility buildings for space heating and hot water generation, whereas the energy demand for cooling is growing year after year. There are more than 150 millions dwellings in Europe. Around 30% are built before 1940, around 45% between 1950 and 1980 and only 25% after 1980. Retrofitting is a means of rectifying existing building deficiencies by improving the standard and the thermal insulation of buildings and/or the replacement of old space conditioning systems by energy-efficient and environmentally sound heating and cooling systems.

In order to realise the ambitious goals for the reduction of fossil primary energy consumption and the related CO_2 emissions to reach the targets of the Kyoto-protocol besides improved energy efficiency the use of renewable energy in the existing building stock have to be addressed in the near future.

On 17 December 2008, the European Parliament adopted the Renewable Energy Directive. It establishes a common framework for the promotion of energy from renewable sources. For the first time, this Directive recognises aerothermal, geothermal and hydrothermal energy as renewable energy source. This directive opens up a major opportunity for further use of heat pumps for heating and cooling of new and existing buildings.

Heat pumps enables the use of ambient heat at a useful temperature level need electricity or other auxiliary energy to function. Therefore, the energy used to drive heat pumps should be deducted from the total usable heat. Aerothermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account for the purposes provided that the final energy output significantly exceeds the primary energy input.

The amount of ambient energy captured by heat pumps to be considered renewable energy E_{res}, shall be calculated in accordance with the following formula:

$$E_{res} = Q_u\left(1 - \frac{1}{\mathrm{SPF}}\right) \tag{1}$$

where: Q_u is the estimated total usable heat delivered by heat pumps; SPF – the estimated average seasonal performance factor for these heat pumps.

Only heat pumps for which SPF>1.15/η shall be taken into account, where η is the ratio between total gross production of electricity and the primary energy consumption for electricity production. For EU-countries Average η=0.4. Meaning that minimum value of seasonal coefficient of performance should be $SPF=COP_{seasonal}>2.875$.

Heat pump enables the use of ecological heat (solar energy accumulated in the soil, water and air) for an economic and ecological heating. For practical use of these energy sources we have to respect the following criteria: sufficient availability, higher accumulation capacity, higher temperature, sufficient regeneration, economical capture, reduced waiting time. In the development of modern constructions with improved thermal insulation and reduced heat demand use heat pumps are a good alternative.

2 Operating principle of heat pump

Heat pump is a thermal installation which is based on a reverse thermodynamic cycle (consumes action energy and produces a thermal effect).

Any heat pump takes heat E_S from a low potential thermal source, at temperature t_s and with an energy action E_A it raises the thermal potential and yielde this heat for a consumer at t_u temperature.

• *Heat source* can be*:*

– a gas or air (oudoor air, warm air from processes of cooling or ventilation, hot gases from industrial processes);

– a liquid called generic water: surface water (river, lake, sea), ground water (underground water, geothermal water), discharged hot water (domestic, recirculated in cooling towers, technological);

– soil (with the advantage of accessibility and the temperature constance at a depth of over 4 m, but with the disadvantage of low heat transfer).

• *Heat consumer.* The heat pump yields thermal energy at a higher temperature is depending on the application of heat consumer. This energy can be used to:

– spaces heating; heating with heat pump who will be related to heating systems that require low temperature: radiant systems (radiant panels, heating from floor), warm air or convective systems (ventilo-convectors);

– water heating (pools, domestic and technologic hot water);

– achivement of technological processes (drying, distillation of solutions, salt concentration).

It is recommended that whenever possible, the heat consumer to be associated with a cold consumer, in which case, the same installation will achieve both effects: the heat production and cold production. This can be performed with either a reversible (heating-cooling) or a double effect (it produces simultaneously heat and cold) installation.

• *Action* e*nergy*. Heat pumps can use to engage different forms of energy:

– electrical energy (electrocompressor installation);

– mechanical energy (mechanical compression installation, with the action energy produced with expansion turbines);

– thermal energy (installation with mechanical compression, absorption or ejection). In this case is required either a fuel feeding the thermal motor of compression installation with an internal combustion motor, or thermochemical compressor digester of absorption installation with direct combustion or a hot fluid (steam, condensate, hot water, warm gases) which supplies the digester of absorption installation or the ejector of ejection installation.

The most used heat pumps plants are those with mechanical compression and absorption.

2.1 Functional scheme and thermodynamic cycle of mechanical compression heat pump

Mechanical vapor compression heat pump works by reverse Carnot cycle, placed in the water vapor domain, but situate above ambient temperature. Figure 1 shows the functional scheme and theoretical thermodynamic cycle of undercooling heat pump. To reduce loss caused by the lamination irreversibility it recourses for inclusion of undercooler in the heat pump scheme with the role to reduce the temperature of saturated liquid refrigerant, below condensation temperature T_c.

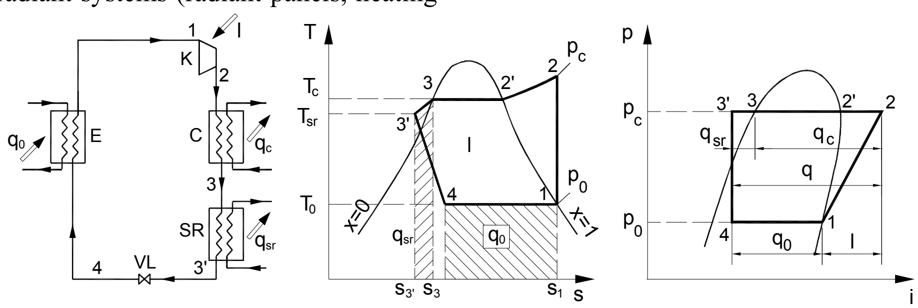

Fig. 1 Functional scheme and thermodynamic cycle of heat pump with undercooling

Functional processes are the following:

1–2: isentropic compression in the compressor K, which leads to increased pressure and temperature from the values corresponding for vaporization p_o, T_o to those of the condensation p_c, $T_2>T_c$ (in the superheated vapour domain);

2–2': isobar cooling in the condenser C at pressure p_c from the temperature T_2 to $T_{2'}= T_c$;

2'–3: isotherm-isobar condensation in the condenser C at pressure p_c and temperature T_c;

3–3': isobar undercooling in the under cooler SR at pressure p_c from temperature T_c at $T_{sr}<T_c$;

3'–4: isentalpic lamination in expansion valve VL, leading the refrigerant from 3' state of the undercooled liquid at p_c, T_{sr} in 4 state of wet vapor at p_o, T_o;

4–1: isotherm-isobar vaporization in the evaporator E at pressure p_o and temperature T_o.

It result the following relationships and graphic meanings of energy exchanges of refrigerant:

– specific cooling power at the agent vaporization:

$$q_o = i_1 - i_4 = T_o(s_1 - s_4) = \text{area } s_4 41 s_1 \qquad (2)$$

– specific heat load at condensation:

$$q_c = i_2 - i_3 = \text{area } s_1 22'3 s_3 s_1 \qquad (3)$$

– specific heat load at undercooling:

$$q_{sr} = i_3 - i_{3'} = \text{area } s_3 33' s_{3'} s_3 \qquad (4)$$

– specific thermal load of the refrigerant:

$$q = q_c + q_{sr} = i_2 - i_{3'} = \text{area } s_1 22'33' s_3 s_1 \qquad (5)$$

– specific work of compression:

$$l = i_2 - i_1 = q - q_o = i_2 - i_{3'} - (i_1 - i_4) \qquad (6)$$

– thermal power of heat pump:

$$Q_{PC} = m\,q \qquad (7)$$

where m is mass flow of the refrigerant.

– coefficient of performance COP or theoretical efficiency ε^{PC} of the heat pump is expressed trough the ratio:

$$\text{COP} = \varepsilon^{PC} = \frac{q}{l} = \frac{i_2 - i_{3'}}{i_1 - i_2} \qquad (8)$$

In heat pumps the undercooling rank $\Delta T_{sr} = T_c - T_{sr}$ can be increased till the achievement of the ambient temperature of the refrigerant liquid, resulting a substantial reduction of loss caused by the irreversibility of the lamination process.

2.2 Earning capacity limit of heat pump with electrocompressor

In this case interfers the global efficiency η_g as a product between the electrical energy production efficiency η_p, its transportation efficiency η_t and the electromotor efficiency η_{em}:

$$\eta_g = \eta_p \eta_t \eta_{em} \qquad (9)$$

Taking into account that the heat pump has an overunit theoretical efficiency, for the evaluation in which way is valued the consumed primare energy is using the sintethic indicator η_s, representing the product:

$$\eta_s = \eta_g \varepsilon^{PC} \qquad (10)$$

which has to satisfy the condition $\eta_s>1$ for justify the use of heat pump

Also, only if the real efficiency $\varepsilon_r^{PC} > 3$ the use of heat pump can be considered.

The maxim value, theoretic possible, of the efficiency ε_c can be obtained in reverse Carnot cycle case depending only on absolute temperature level of the hot source T_c and the cold one T_o:

$$\varepsilon_c = \frac{T_c}{T_c - T_o} \qquad (11)$$

The real efficiency ε_r^{PC} of the heat pump is lower than the theoretical maximum one ε_c, representing 40...60% of its vaue. Results that for ε_r^{PC} to have the value 3, ε_c must be at least 6...7.

If T_c = 70 °C, T_o must be minimum 12...20°C, achieved condition by the major part of thermal waste. Only in case of the air heat pump, as energy source, we can talk about a limitation of use the plant during the coldest days of the year.

3 Performances of heat pump

The performances of heat pump and building – heating/cooling installation system is determined based on economical and energy indicators of these systems. The opportunity to implement a heat pump in a heating/cooling system results on both energy criteria and the economic.

- *Economical indicators.* Usually the heat pump HP realise a fuel economy ΔC (operating expenses) comparatively of the classical system with thermal station (TS), which is dependent on the type of heat pump. On the other hand, heat pumps involve an additional investment I_{HP} from the classical system I_{TS}, which produces the same amount of heat.

Thus, it can be determined the recovery time TR, in years, to increase investment, $\Delta I=I_{HP}-I_{TS}$, taking into account the operation economy realised through low fuel consumption $\Delta C=C_{TS}-C_{HP}$:

$$TR = \frac{\Delta I}{\Delta C} \le TR_n \qquad (12)$$

where TR_n is normal recovery time.

It is estimated that for TR_n a number 8...10 years is acceptable, but this limit varies depending on the country's energy policy and environmental requirements.

• *Energetical indicators.* The operation of a heat pump is characterized by the coefficient of performance COP or thermal efficiency ε^{PC}, defined as the ratio between useful effect produced (useful thermal energy E_U) and energy consumed to obtain it (action energy E_A)

$$\mathrm{COP} = \varepsilon^{PC} = \frac{E_U}{E_A} \tag{13}$$

From the energy balance of the heat pump:

$$E_U = E_S + E_A \tag{14}$$

can highlight the link between the efficiency of a plant working as a heat pump (ε^{PC}) and as a refrigeration plant (ε^{IF}):

$$\varepsilon^{PC} = \frac{E_S + E_A}{E_A} = 1 + \frac{E_S}{E_A} = 1 + \varepsilon^{IF} \tag{15}$$

The most effective systems are those which use simultaneously the produced heat and the adjacent refrigeration effect, in which case the total efficiency is:

$$\varepsilon^{PC+IF} = \frac{E_U + E_S}{E_A} = \frac{E_S + E_A + E_S}{E_A} = \varepsilon^{PC} + \varepsilon^{IF} \tag{16}$$

If you take into account the Π_j e-nergy losses that are accompanying both the accumulation and release heat from the real processes, the efficiency becomes real ε_r^{PC} and its expression is:

$$\varepsilon_r^{PC} = \frac{T_c}{T_c - T_o}(1 - \Sigma\Pi_j) \tag{17}$$

where T_c and T_o are the condensation and vaporization absolute temperatures of refrigerants.

In figure 2 is represented the real efficiency variation of heat pumps according to the source temperature t_o and temperature t at the consumer.

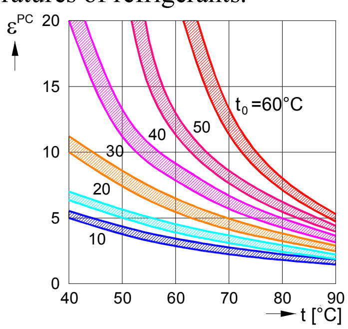

Fig. 2 Variation of heat pumps efficiency

To determine the real efficiency of the heat pump with electrocompressor we can use the relation bellow [9]:

$$\varepsilon_r^{PC} = \frac{T + \Delta t}{T + \Delta t - (T_o - \Delta t_o)} \eta_r \eta_i \eta_m \eta_{em} + \eta_m \eta_{em} (1 - \eta_i) \tag{18}$$

where:

$$\eta_r = 1{,}666 - 0{,}004(T_o - \Delta t_o) - 0{,}00625(T + \Delta t) \tag{19}$$

$$\eta_i = \left(0{,}425 + \frac{0{,}493 Q_{PC}}{1{,}16 Q_{PC} + 0{,}06}\right)\left(3{,}23 - 1{,}835 \frac{T + \Delta t}{T_o - \Delta t_o}\right) \tag{20}$$

$$\eta_m = 0{,}85 + \frac{0{,}158 Q_{PC}}{1{,}16 Q_{PC} + 0{,}1513 \dfrac{T + \Delta t}{(T + \Delta t) - (T_o - \Delta t_o)}} \tag{21}$$

$$\eta_{em} = 0{,}85 + \frac{0{,}139 Q_{PC}}{1{,}335 Q_{PC} + 0{,}0904 \dfrac{T + \Delta t}{(T + \Delta t) - (T_o - \Delta t_o)}} \tag{22}$$

in which: T, T_o are the hot and cold source absolute temperatures; Δt, Δt_o – temperature differences between condensation temperature and hot source temperature, respectively, between cold source temperature and vaporization temperature; η_r – efficiency of the real cycle toward a reference Carnot cycle; η_i, η_m – internal and mechanical efficiency of the compressor; η_{em} – electromotor efficiency; Q_{PC} – heat pump thermal power

Another energetical indicator for heat pumps is the specific consumption of electricity w^{PC}, in kW/GJ:

$$w^{PC} = \frac{10^3}{3{,}6 \varepsilon_r^{PC}} \tag{23}$$

In figure 3 is illustrated the electricity consumption for heat pumps depending on the heat source temperature t_o and the consumer temperature t.

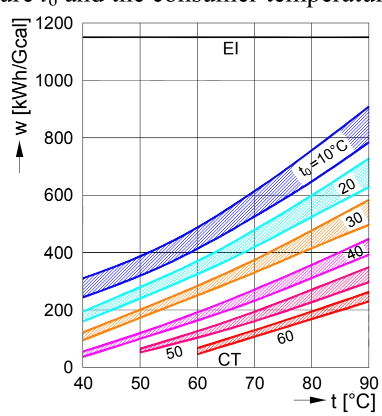

Fig. 3 Specific electricity consumption for the heat production

The sizing factor (SF = α^{PC} = $Q_{PC}/Q_{\max}$) of the heat pump is defined as ratio of the heat pump capacity Q_{PC} to the maximum heating demand $Q_{\max}$ and can be optimized in terms of energy and economic, depending on the source temperature and the used adjustment schedule.

The energetical indicators of heat pumps are determined as average values, taking into account the annual heat consumption variation.

In figure 4 is represented variation of the average annual electric energy specific consumption, in function of α^{PC} and different graphics adjustments.

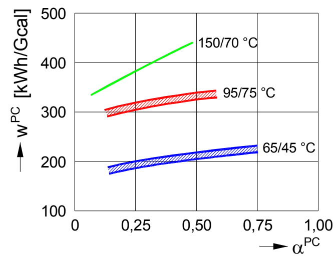

Fig. 4 Variation of the average annual electricity specific consumption

The annual fuel economy variation ΔB, obtained by using heat pump, expressed as percentage of total annual fuel consumption in a referencial classic system is presented in figure 5.

In order to properly compare the performances of various heat pumps types, have to uniform the action energy. In this sense, is reported the useful heat delivered annually $Q_{u,year}$ at annual equivalent fuel consumption $B_{fe,year}$, necessary for driving power production, achieving the degree of fuel use φ_{year}, in kW/kg:

$$\varphi_{year} = \frac{Q_{u,\, year}}{B_{fe,\, year}} \tag{24}$$

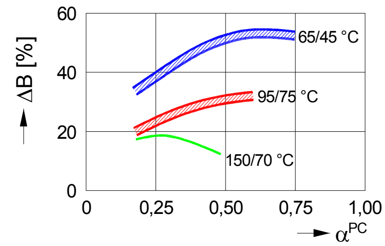

Fig. 5 Variation of annual fuel economy

The fuel economy depends by heat pump type, according to table 1.

Table 1. Energy analysis of heat production

Nr crt.	Plant type	Degree of fuel use φ_{year} [kW/kg]	Primary energy E_p [%]	Fuel economy ΔC [%]
0	1	2	3	4
1	Gas boiler	0.800	125.00	0
2	Heat pump with electrocompressor	1.083	92.34	–32.66
3	Heat pump with electrocompressor and thermal boiler	0.969	103.20	–21.80
4	Heat pump with thermal motor compressor	1.416	70.62	–54.38
5	Absorbtion heat pump	1.219	82.03	–42.97
6	Ejection heat pump	0.970	103.09	–21.91

4 Description of underground water heat pump "Geoterm" system

For most heating/cooling systems with heat pump about half of the initial investments are the outside facilities (deep drilling or cutting at 1...2 m on large areas). The open classical systems that use underground water as a heat source have the low costs, but with some limitations on the big flow of underground water, the need for appropriate water and clogging of injection drilling with appreciable sediment quantities.

The "Geoterm" system tested in laboratory of the Building Services Department of the "Politehnica" University of Timişoara, removes these disadvantages by using a special built heat exchanger (fig. 6), placed in a absorbing well with 1m diameter and depth of 2.5 m. The construction of such a heat exchanger consists of a set of four coaxial coil made of high density polyethylene tubes, immersed in a cylindrical reservoir (0.8 m diameter and 1.2 m height) supplied with underground water at bottom side.

Through the secondary circuit of the heat exchanger (toward the heat pump) is circulated a solution of water and antifreeze, which enters in heat pump with 0°C and comes out with -2 °C, trained by circulation pump with a flow rate of 0.94 l/s. The heat transfer between glycol solution and underground water is made by the movement of the two fluids from the heat exchange surface (polyethylene tube). Glycol flow in tubes is ensured by the circulation pump within the heat pump. Outside the coils, the undeground water from the cylindrical reservoir is involved in a flow among the spires of coils, by a submersible pump. Pressure loss on the secondary circuit of the heat exchanger, relatively small, allows use a reduced power circulation pump for glycol, with direct effect on increasing overall performance of the system.

Heat pump used in conjunction with the intermediate heat exchanger is a ground-water pump of 10 kW, with the coefficient of performance COP = 4.

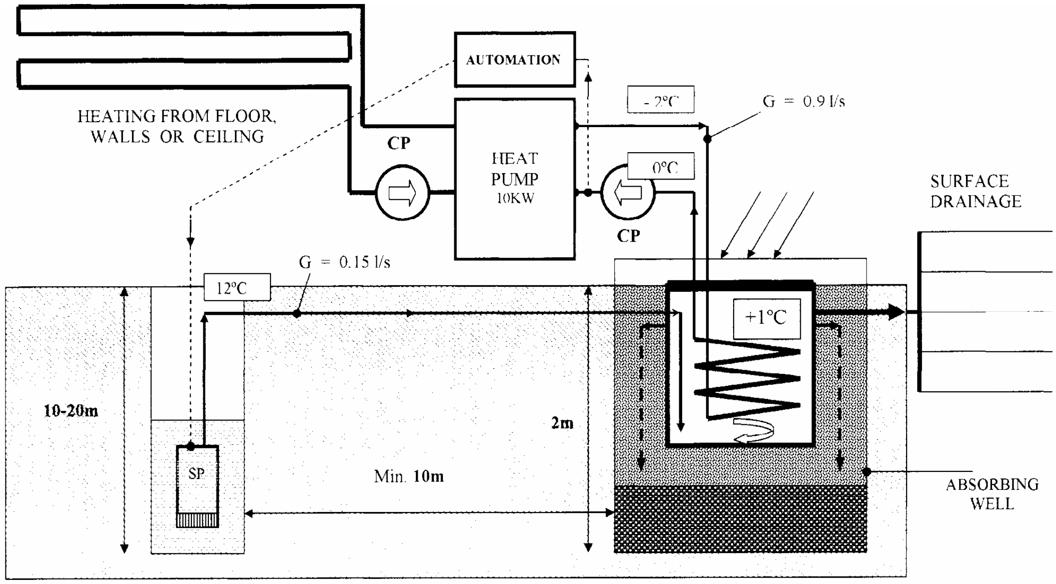

Fig. 6 Underground water heat pump "Geoterm" system

In primary circuit of the exchanger, underground water enters with a temperature of 12 °C and is evacuated to approx. 1 °C (heat regime). Since the temperature drop is 11 °C compared to 4 °C in the usual case, it is possible to obtain the same thermal power with a underground water flow nearly three times lower. Consequently, the sediments in water are reduced because they are deposited on the bottom of heat exchanger reservoir, where periodically can be removed easily. The pressure loss on the primary circuit of the exchanger is 26 kPa, for mentioned flow rate. The heat exchange is realised out mainly by underground water supply, and also, the heat exchanged directly with the soil around the absorbing well is important.

The underground water, after it has snapped (heating system) or received (cooling system) heat is evacuated through the top of exchanger, then, by gravity in the absorbing well. Where the absorbing well cannot retrieve all underground water flow (groundwater aquifers is close by surface, during the very cold or very hot periods) is recommended the surface drainage through a network of perforated pipes buried at 50 ... 80 cm.

Regardless of the outdoor air and soil temperature, the heat pump will always operate in the same optimum temperatures because of the automation.

During summer, the intermediate heat exchanger can operate in a passive cooling regime when the heat pump only produces domestic hot water using heat extracted from the air-conditioned space. In this case heat carrier that circulates in floor, walls or ceiling is moved with the circulation pump directly to the intermediate exchanger.

5 Operating regimes of heat pump

The operating regime of the heat pump is adapted to the existing heating system of buildings. If the forward temperature is higher than the maximum forward temperature of heat pump (55 ^{o}C), then the heat pump will only operate in addition to the classical sources of heat. In new buildings will elect a distribution system with a maximum forward temperature of 35 ^{o}C.

Technically can be distinguish the following regimes of operation:

- *Monovalent regime*. In case of the monovalent regime, the heat pump system assures the entire heat demand of the building. Distribution system should be designed for a forward temperature below the maximum forward temperature of the heat pump.
- *Bivalent regime.* A bivalent heating plant has two sources of heat. Heat pump with electrical action is combined with at least one heat source for solid, liquid or gaseous fuels. This regime can be bivalent parallel (heat pump operates simultaneously with another heat source) or bivalent alternative (works either the heat pump system or other heat source).
- *Monoenergetic regime* is a bivalent operation regime in which the second heat source (auxiliary source) functions with the same type of energy (electricity) like the heat pump.

To make possible the economical operation of the heating system with heat pumps, in some countries, the supplier of current provides special electricity tariffs for heat pumps. These prices usually assume that the electricity supply for heat pumps can be interrupted while the network is overbusy. For example, electricity supply for the heat pump systems with monovalent operating regim, may be discontinued in 24 hours three times for more than two hours. Operating time between two interruptions should not be lower than the previous interruption. In the case of heat pump systems with bivalent operation, the electricity supply may be interrupted during the heating period up to 960 hours.

For existing buildings is recommended the bivalent operating regime, because a heat source exists, which usually can be used further to cover the peak loads of cold winter days with forward temperatures of over 55 ^{o}C.

For new buildings has proved useful the monovalent operating regime, which may be interrupted. Heat pump can cover the annual heat demand, and the periods of interruption do not lead to disturbances in operation because, for example, heating from floor may exceed periods without interruption to ascertain changes in comfort temperature.

6 Better energy efficiency with combined heating and cooling by heat pumps

The possibilities of heat pump solutions in combined cooling and heating systems have been unclear for a major part of the designers of the air-conditioning systems. Therefore, a survey was made to find out a proper dimensioning and disseminate the know-how. More general study was made find out the influence of different factors.

A general study was carried out with a simple modelling tool. Because the goal was to compare different systems and sizing of the heat pump, the required heating and cooling capacities were calculated as the time-series using a simple dependence on outdoor temperature and solar radiation. Variations of a heat source temperature of the heat pump are important for the annual COP. The presumed curves and the influence on COP are shown in figure 7.

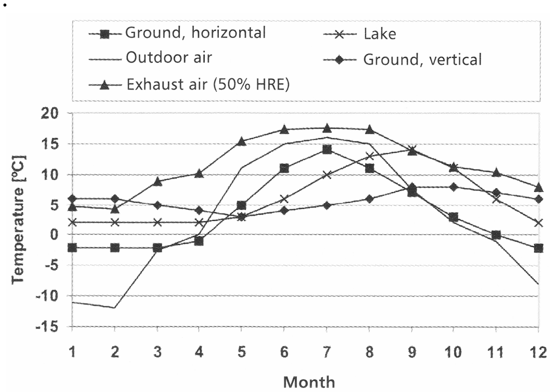

Fig. 7 Temperature profiles of heat sources as used in modelling

When the capacity of the heat pump (SF) increases COP decreases (fig. 8) because a greater part of heating demand is produced under less favourable conditions, at lower heat source temperature. If the heat pump is dimensioned only for air conditioning cooling duty the sizing factor here is 40%.

Free cooling using the low temperature of the heat source is an effective way to decrease energy condumption of the compressor-based cooling. The temperature level of the heat source and the annual cooling demend profile determine how big part can be covered by free cooling as illustrated in figure 9. Also, the temperature level of the cooling-water network has an essential influence: The higher the temperature, the bigger part can be produced by free cooling.

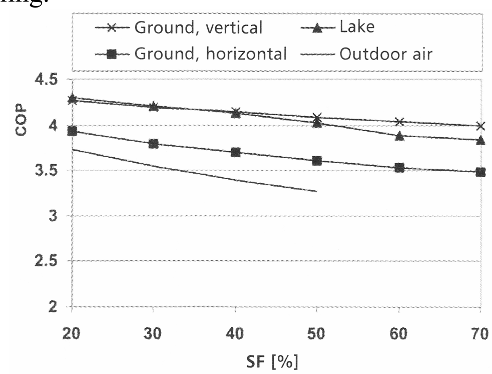

Fig. 8 Annual COP versus sizing factor

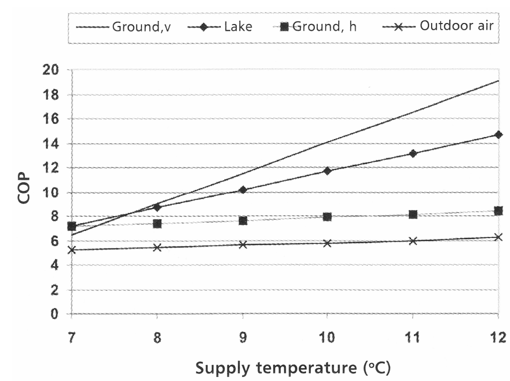

Fig. 9 Influence of supply temperature of cooling water-network on COP of cooling

Exhaust air as a heat source utilizes heat after the normal heat recovery heat exchanger. When the efficiency on the heat exchanger is increased, the temperature before the evaporator falls and required capacity of the heat pump decreases. However, the electricity usage is almost constant, because COP decreases as shown in principle in figure 10. The main point is that the total energy consumption decreases. In the model of the evaporator, also the energy loss caused by defrosting was calculated. The method was calculation the amount of freezing moisture and evaluation of the heat needed to melt the frost with a given efficiency.

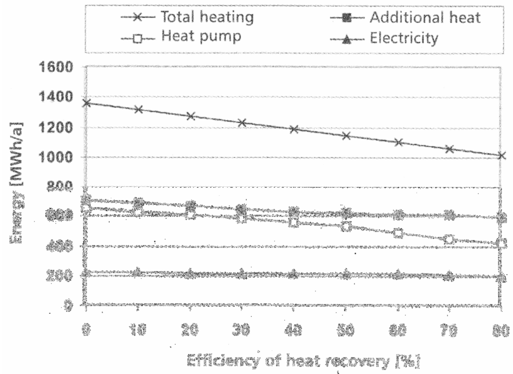

Fig. 10 Influence of efficiency of heat recovery on energy consumption

7 Comparative economic analysis of heating solutions for a building

• *Assumptions for calculation.* A study is performed for the heating of a living building in rural areas with a water-water heat pump, using as heat source the underground water comparative to other sources of primary energy.

The building with useful surface of 240 m^2 (basement-floor, ground-floor, floor, and bridge) is heated from 1993 with radiators from thermal station with gas-oil. Indoor air temperatures were considered in accordance with the wishes of the client: +20 °C for the stairway and annex spaces; +22 °C for day rooms and bedrooms; 24 °C for baths. Construction materials which distinguish heated spaces are: 50 cm brick for exterior walls, concrete 10 cm and 15 cm layer of expanded polystyrene insulation for the bridging, double glazing in oak. Exterior walls will be isolated from the outside with expanded polystyrene (10 cm).

Calculation of heat demand Q_{nec} was performed for the existing building envelope (exterior walls without insulation) and after thermal rehabilitation of it (exterior walls insulated with 10 cm expanded polystyrene), for more outdoor air temperatures (table 2) in order to choose efficient heat source.

Table 2. Heat demand for heating

t_e [°C]	Q_{nec} [kW]	
	Existent envelope	Rehabilitated envelope
+5	18.9	13.6
0	20.2	15.5
–5	21.6	17.4
–10	23.0	18.3
–15	24.3	19.1
–20	25.6	21.1

For the preparation of domestic hot water is necessary to consider a heat Q_{dhw} = 3 kW (3 persons, 3 bathrooms and a kitchen).

• *Solution proposed.* Building heating is realised as follows:

– heating of living spaces (living rooms, bedrooms, stairway) with the floor convector-radiator;

– bathroom heating with radiators (towel– port);

– hot water temperature to radiators and convector–radiator: 50/40 °C;

– for supply of radiators and convector-radiators are used distributor/collector systems;

– distribution network for radiators and convector–radiators, pexal made, is placed at ceiling, basement-floor, ground-floor and floor.

The heat demand of building will be provided by a heat pump type Thermia Eko 180 and a boiler with the capacity of 300 liters. Mechanical compression heat pump (scroll compressor) operates with ecological refrigerant R404A. The heat source is the groundwater aquifers with minimum temperature of 10 °C.

In the operating conditions with t_o = 8 °C and t_c = 50°C the thermal power of heat pump is Q_{PC} = 21 kW. It finds that this thermal power assure part of the building heat demand, only for outdoor temperatures higher than –5 °C, in the actual situation, and almost entirely (even for the outdoor temperature of –20 °C), in conditions of thermal rehabilitated envelope (exterior walls isolated additional). To assure the rest of heat demand (heating and preparation of domestic hot water) heat pump is equipped with 3 electrical resistance by 3 kW, which operate automatically, depending on the set indoor temperature.

For flow rate control in the hot water distribution network from the heating cicuit, there are provided the following measures:

– a first adjustment of the flows rate that are supplied the terminal units (radiators or convector-radiators), achieved by progressive reduction of the pipe diameters;

– base adjustment, achieved through the regulating valves of flow for each column;

– final adjustment at the terminal units, developed by the thermostat valves set at the comfort temperature in each room.

• *Economical analysis.* Comparing the solution described for building heating with other possible variants of primary energy sources (LPG, gas-oil and natural gas) results a superior investment for heat pump, but also an economy in operating costs, which enable the recovery of additional investment.

In tables 3 and 4 are presented the necessary investments and operating costs over a period of 10 years for the considered variants.

Table 3. Investment costs I, in €, for heat pump (HP) and different thermal boilers.

Solution components	HP	Thermal boiler with fuel:		
		LPG	Gas-oil	Natural gas
0	1	2	3	4
Heat pump/Boiler	7700	3000	3000	3000
Underground water captation	4900	–	–	–
Heat exchanger	1300	–	–	–
Circulation pumps	1200	–	–	–
Fuel tank	–	3500	3500	–
Gas connection	–	–	–	4000
Total	15100	6500	6500	7000

Table 4. Operating expenses for heat pump (HP) and different thermal boilers.

Solution characteristics	HP	Thermal boiler with fuel:		
		LPG	Gas-oil	Natural gas
0	1	2	3	4
Thermal power, [kW]	21+9	24	24	24
Fuel calorific power, [kW/l]	–	6.30	10.0	9.44
TS Efficiency / HP- COP	2,33	0.90	0.85	0.90
Hour consumption (fuel, [l/h] / electric energy, [kW])	9.00	4.23	3.02	2.84
Annual operating, [h/year]	1870*)	1700	1700	1700
Fuel price, [€/l] / Electricity price, [€/kWh]	0.087	0.500	0.900	0.300
Annual consumption, [l/an; kWh/an]	16830	7191	5134	4828
Annual energy cost, [€/an]	1464	3595.5	4620.5	1448.5
Estimated energy price increase in 10 years	1.30	1.40	1.40	2.00
Operating expenses (10 years), C [€]	1903.2	5033.7	6468.7	2897.0
*) Annual operation of electrical resistances is considered 10% of the normal operation period, so at the 1700 hours/year is adding 170 hours/year.				

Results the recovery time of additional investment for heat pump, compared with thermal boilers:

– toward boiler to LPG:

$$TR = \frac{I_{HP} - I_{TS,\text{LPG}}}{C_{TS,\text{LPG}} - C_{HP}} = \frac{15100 - 6500}{5033.7 - 1903.2} = 2.74 \text{ years}$$

– toward gas-oil boiler:

$$TR = \frac{I_{HP} - I_{TS,\text{gas-oil}}}{C_{TS,\text{gas-oil}} - C_{HP}} = \frac{15100 - 6500}{6468.7 - 1903.2} = 1.88 \text{ years}$$

– toward natural gas boiler:

$$TR = \frac{I_{HP} - I_{TS,\text{natural gas}}}{C_{TS,\text{natural gas}} - C_{HP}} = \frac{15100 - 7000}{2897.0 - 1903.2} = 8.15 \text{ years}$$

It is noted that compared to any of the heating solutions to boilers, heating with water-water heat pump has a recovery period of investment *TR* smaller than normal recovery period TR_n, of 8 ... 10 years.

8 Conclusions

Correct adaptation of the heat source and the heating system for operating regime of heat pumps, leads to safe and economic operation of the heating system using heat pumps.

Heat pump provides the necessary technical conditions for efficient use of solar heat for heating and production of domestic hot water.

Heating installations with heat pumps produces minimum energy consumption in operation and are certainly a solution for energy optimization of buildings.

The heat pump mode requires some additional investments. If the capacity of the heat pump is selected larger than the condensing capacity in the pure refrigeration mode, also the additional capacity costs have to be covered by the savings in energy costs.

A combined cooling and heating system with a heat pump is always more effective than a traditional system if its requirements are taken into the consideration in the design process. For renovation, the applicability is more limited and always depending on the case.

The main barrier for the use of heat pumps for retrofitting is the high distribution temperature of conventional heating systems in existing residential buildings with design temperatures up to 70 – 90 °C which is too high for the present heat pump generation with maximum, economically acceptable heat distribution temperature of around 55 °C. Besides the application of existing heat pumps in already improved standard buildings with reduced heat demand, the development and market introduction of new high temperature heat pumps is a mayor task for the replacement of conventional heating systems with heat pumps in existing buildings.

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