Member of **EGEC – European Geothermal Energy Council**
Member of **Geoexchange Heat Pump Consortium USA**
Member of **IGSHPA - International Ground Source Heat Pumps Association**

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ABOUT HEAT PUMPS AND RES H/C REGULATIONS

Content

The initiative of discussing on the topic of heat pumps performance is extremely useful and urgent. The motivations concern the confusions created by the lack of proper and concise definitions, also unanimous accepted. The **Romanian Geoexchange Society** suggests the following subjects for discussion:

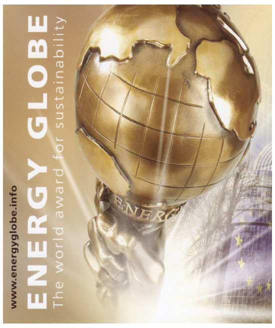
1. The correct definition of heat pumps by their source

A heat pump is a thermal working machine, which uses driving energy (electric energy or heat) as driving power to transfer heat from a low thermal potential - usually without any use, positioned in the vicinity of the environment and called „heat source" - to another heat source at a high thermal potential, at which the heat can be used.

According to the nature of the "thermal source", the following cases can be observed:

1.1 Air as Thermal Source

In this case, the Heat Pump transfers heat from the exterior air to the interior air or from exterior air directly to a hot water installation. Therefore, the denominations for the air source heat pump are:



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- air-to-air heat pump, and
- air-to-water heat pump.

This thermal source has a big **advantage** called "free accessibility" (it doesn't need special investments for accessing/using the source), but it also has more **disadvantages** defined as follows: dependence on the daily variation of the air temperature; very low potential of the source exactly when it is needed the most (during winter time, when the temperatures are below 0^{o}C) and the low convective heat transfer coefficient that demands large heat exchange surface for the evaporator (hence the installed thermal power is limited).

1.2 Ground as Thermal Source

In this case, the heat pump practically takes heat from a "liquid", generically called "water", the liquid being in contact with the ground. The connection can be direct, meaning "the liquid" is surface water (coming from a lake, a river, or a see) or the "liquid" is underground water (from water bearing layers - aquifers). In the first case, the surface water has a temperature depending on both thermal sources (the outdoor air and the ground), and in the second case the deep underground water has a constant temperature which is practically equal to the ground temperature (over 14^{o}C and under 20^{o}C) depending on the depth of the underground water and its flowing speed. The two cases are both in the category of ground source heat pump - GSHP with open loop. The denomination comes from the fact that the water is extracted from the thermal source, shallow or deep, thermally treated and then returned to the source. Water's entry temperature is equal to ground temperature.

The connection between the thermal source and the „liquid" is usually indirect. We refer here to closed loop circuits, in which the water is on controlled movement between the ground heat exchanger and the heat pump's evaporator. It is the case of the ground heat exchangers (horizontal or vertical) or the heat exchangers immersed in water (a lake, a river, the sea), where the „liquid" has an entry temperature in the thermal machine lower by 3÷5^{o}C than the ground temperature. For most of the above-mentioned cases, the thermal source has a great **advantage**, and that is the temperature's „constancy", not depending at all or little on the atmospheric air. The **disadvantage** of this thermal source is the "accessibility cost", meaning the obligation to invest in a ground heat exchanger, in a closed loop or an open loop.

Hence, the GSHP has in the cooling cycle an evaporator fed by water (in an open loop circuit or in a closed loop circuit) and a condenser that can be chilled either by air or by water. Thus the diversity of GSHP and that is:

- Water-to-Air Heat Pumps, and
- Water –to-Water Heat Pumps.

Obviously, in the case of Water-to-Air Heat Pumps, their role is to provide direct heating to the interior air of a building, and in the case of Water-to-Water Heat Pumps to provide indirect heating of the building by producing a thermal heated agent that is available for heating. Both types of shallow geothermal heat pumps can produce simultaneously domestic water thanks to a de-super-heater that can be included, at request, in the cooling cycle of the thermal machinery.

2. Definition of Driving Energy for the Heat Pumps

The most common Heat Pumps are those using electricity as driving energy (thermal working machines, with cooling thermodynamic cycle, with electro-compressor). The main **advantage** and reasons are accessibility and simplicity. It is accepted the main **disadvantage** related to the cost of electricity coming from low efficiency power plants and the eventual pollution by generating greenhouse effect gases. We refer to the territory of a country, where the main role in producing electricity is taken by the fossil fuel power plants (based on coal, petroleum and natural gas).

3. The energetic indicator of the Heat Pumps.

A Heat Pump from the categories Air-to-Air, Air-to-Water, Water-to-Air or Water-to-Water, having atmospheric air or ground as heat source is characterized energetically speaking, by a Coefficient of Performance - **COP**. This is defined as an improper fraction in which the numerator is the useful energy (provided heat) and denominator is the driving energy (used energy).

As the driving energy is the electric energy consumed by the compressor during the thermodynamic cooling cycle, it means that the COP-s value indicate the multiplication factor for the electrical energy consumed for obtaining high potential energy from low potential energy. If the energy extracted from the ground heat exchanger of the GSHP case is E_S (Source's Energy) and the compressing energy of the thermodynamic cooling cycle, respectively the energy used by the compressor, is E_A (Driving Power), then:

$$COP = \frac{E_S + E_A}{E_A} = (1 + \frac{E_S}{E_A})[\frac{kWh}{kWh}]$$

If we impose for a GSHP to extract from the source a thermal energy at least equal with the double value of the electrical energy used, then the Coefficient of Performance of a GSHP cannot be lower than 3. If we additionally demand that the temperature of the heated "fluid" (hot air or hot water) obtained at the condenser of the thermal machine to be superior to the value of 35^oC, in steady state regime, then we will be certain that the GSHP saves primary energy and we have a real reduction effect of CO_2 emissions.

For these imposed conditions, over 90% of the GSHP producers indicate values of the COP over 3.1 when the entering water temperature EWT (the geothermal source flow) is 0^oC. Such temperature value of the geothermal source flow is possible to obtain for most of the ground heat exchange systems at very low outdoor air temperatures (for example: -12°C, -15°C, -18°C, -21°C – temperatures used in calculation for the climatic zones I÷IV from Romania, Annex 1), something impossible to reach for the HP with atmospheric air as heat source. So, the two thermal sources, the ground source and the atmospheric air source cannot have the same impositions concerning the value of the COP. For example, for the 0^oC temperature of the environment and for the over 35^oC temperature of the hot water, an Air Source Heat Pump has the value of the COP under 2.5. A value of 3.5 for the COP can be reached by a Heat Pump in the Air-Water system for an exterior temperature of about 10^oC. In other words, a GHP can ensure by itself the required thermal necessity of a building, even if the exterior temperature lowers a lot below 0^oC, while a Heat Pump having the air as heat source can produce the same effect only in bivalent systems (always together with a second thermal source).

4. About the COP of a HVAC thermal system in winter

In nowadays Europe, the European Directive no. 91/2002/CE (regarding the energetic performance of buildings) and Directive 2006/32/CE (regarding energetic efficiency for final users of energetic services), demand to classify a building in an Energy Class defined by its annual energy consumption (kWh/m².year) for UTILITIES, the heating energy consumption being placed on an important level. Heating energy consumption depends on a great basis on the thermal insulation level of the analyzed building, and also in a great matter it depends on the heating production system.

In other words, the COP of a Heat Pump is important, but much more important is the COP of the whole system to whom the HP also belongs. Under this aspect, exact definitions are needed regarding the Coefficient of performance of a system, by system meaning the building + thermal installation as a whole. This system is studied in a dynamic regime during a whole year, trying to determine an energetically performance indicator called the "Heating Seasonal Performance Factor" - **HSPF**.

In Thermodynamics, the Coefficient of performance COP for a HP has an instantaneous signification (for the thermodynamic cycle of the HP), while in current practice we take into consideration the thermodynamic performance over a certain period of time – for heating or cooling. Therefore is needed to introduce this energy performance indicator which should take into consideration the energy exchanges for a certain operating period.

In our opinion, we must also take into account, when engineering a HVAC system, the possibility of using the same system for cooling the building too. The Heat Pumps are thermal machines capable of working according to the reversible cooling cycles, and are able to cover such requirement at full potential. Therefore, they are capable to assure heating, ventilation (treat the fresh air), air-conditioning and preparing domestic hot water, meaning they can cover the load for a HVAC System required for a building during the whole year.

In the heating season of the building - when the HVAC system includes heat pumps - the coefficient of performance of the HVAC is called the "Heating Seasonal Performance Factor" - HSPF. This HSPF is a fraction having as numerator the following terms:

- the heat extracted from the renewable source;
- the caloric equivalent of the electric energy used in the compression process of the cooling thermodynamic cycle;
- the caloric equivalent of a fractional part from the electric energy used by the circulation pumps;
- the caloric equivalent of a fractional part from the air ventilators;
- the above mentioned being some of the most important electrical components of a HVAC system of a building.

The Heating Seasonal Performance Factor takes into account the annual variation of the outdoor and indoor climate conditions, and its value must remain superior to an accepted minimal value that, in our opinion, must be of 2.5. This value is reasonable and can be assimilated by all systems with renewable thermal sources, as by Heat Pumps with outdoor air as heat source and Geothermal Heat Pumps, but this condition is not sufficient unless the building and its HVAC installations are positioned both in an Energy Class with a maximal accepted annual specific consumption. For instance, for office buildings, if Heat Pumps with renewable source participate in the production of heating, ventilation and domestic hot water, we suggest that the maximum specific indicator should be about 243 kWh/(m²*year). Our suggestion takes into consideration the energy efficiency classes imposed by the **European Directive no. 91/2002/CE** and the reference values presented in annex 2.

After some research, for a HVAC System having a **HSPF** of 3.5 (frequently obtained in the IVth climatic area - annex 2), the resulted annual electricity consumption resulted will be of maximum 69.4 kWh/(m²*year), saving approximately 174 kWh/(m²*year), energy coming from classic sources. Such a strategy leads to a reduction of more than 71% of the energy consumption coming from conventional sources (the fraction 174 kWh/(m²*year)/243 kWh/(m²*year), being accompanied by a reduction of the CO_2 emissions by approximately 40 kgCO_2/(m^2*year). This is due to the fact that the difference 243 kWh/m².year – 69.4 kWh/m².year = 173.6 kWh/m².year represents a conventional fuel with an emission factor of 0.224 kg.CO_2/ m^2.year, calculated for the Romanian structure of the primary energy sources used for producing heat and electricity. The statistics for the year 2003 show that the primary energy comes mostly from brown coal and hydrocarbons - 68%, and from nuclear energy - 9%.

It is obvious that the results regarding the fossil fuel savings and the reduction of the volume of greenhouse effect gases can be even more spectacular for the HVAC systems using geothermal heat pumps, due to the higher values of their coefficients of performance (greater than 4).

5. The cooling efficiency of Heat Pumps

The **European Directive no. 91/2002/CE** considers the annual consumption of energy for heating, ventilation and domestic hot water just a part of the UTILITIES in a building, air-conditioning or lighting being the other components that play a role in the energetic evaluation of a building. In countries like Romania the passive cooling is not a feasible solution for buildings – due to the recent climate changes.

In Romania various types of cooling installations are used for ventilating and air-conditioning the buildings, the ones with mechanical compressors being the most frequent. They are a part of the Air-to-Air family (mono splits, dual splits or multi splits) and Air-to-Water family (chillers producing cold water with the temperatures 7°C/12°C). In the last 10 years the GSHP joined the family. Being able to work after the reversible cooling thermodynamic cycles, the thermal machines "connected" to the ground transfer the exceeding thermal energy from the building into the ground. In this way, they provide to the ground during summer time an amount of the energy they extract from the ground during winter time.

The cooling efficiency of the thermal machine (coupled to air or ground heat source) is known in the American practice as the Energy Efficiency Ratio - **EER**. This coefficient is a fraction having at the numerator the quantity of heat absorbed in the cooling cycle E_{ab} (heat coming from the air-conditioned area), and at the denominator it has the compression energy consumed during the cooling cycle E_A (driving energy). All the energy quantities defining the EER are integrated for the functioning period of the heat pump as a cooling machine, meaning the whole period of time when conditioning (cooling and air drying) is needed.

$$EER = \frac{E_{ab}}{E_A}[\frac{kWh}{kWh}]$$

In USA over 90% of the manufacturers of Water-to-Water HP have established that the cooling efficiency of the GSHP in the thermal interval EWT ("Evaporator Water Temperature" - the water being fed into the evaporator of the thermal machine) 20°C÷30°C, has the value of 5.5÷6, meaning that the multiplication factor of the electric energy consumed for refrigerant compression reported to the extracted heat is higher than 5.5:1. The value is independent or very little dependent on the temperature of the environment, a situation completely different compared to the cooling devices named "classic", with outdoor air as heat source, whose coefficient EER is lower as the temperature of the atmospheric air rises, for example in July – August, when the need for cooling is maximum.

6. About the COP of a HVAC system in summer

Accepting what was established at chapter 4 regarding the HVAC System and the Heating Seasonal Performance Factor – HSPF, we will define a COP of the HVAC system in summer time, the so-called "Cooling Seasonal Performance Factor" - **CSPF**. This coefficient is a fraction having the numerator as the total heat gain of the building (forming the cooling application for the building) integrated over the whole cooling period, added with the caloric equivalent of fractional parts from pumping energy and ventilation energy of the building, and at the denominator the total consumption of the electric energy for the HVAC system, including the electrical energy used for pumping the liquid in the ground heat exchanger – all these also integrated over the whole cooling period.

According to the current practice in Romania, we believe that the HVAC systems with Geothermal HP obtain during the summer season a **CSPF with a averrage value of minimum 4**, which is 2 times higher than that of the classic cooling systems, systems that use outdoor air to cool down the condenser.

But it is not enough to impose that minimal value of 4 for the CSPF, if we do not limit simultaneously also the value of the **maximum energy consumption**, the energy used by a building during a year in the HVAC ventilation and indoor air-conditioning system.

Our opinion is that this value must be different from country to country inside the European Union, **depending on the geographical positioning of the country**.

For the Romanian case, the green area (high energy efficiency, class C) on the scale for energy classification for cooling a building (AC – Air Conditioning) in the IVth climatic area (Annex 2) will have the limit value of 146 kWh/m²year. For this value, the HVAC system using shallow geothermal pumps with CSPH=4.5 can use a maximum of 33 kWh/m²year electrical energy (report 146 kWh: 4.5) instead of an approximately value of 73 kWh/m² *year electricity required when we use compression cooling installations having **CSPH**=2 (with outdoor air source). We obtain savings of half of energetic resource and an important decrease of the annual CO_2 emissions.

7. Conclusions

There are notable performance differences between Heat Pumps with renewable source that use outdoor air and the ones that **use the ground as heat source**. Both resources save fossil type fuels and decrease the CO_2 emissions, but:

- **HP with outdoor air as heat source cannot ensure the whole required quantity of heating for a building in winter time**, reason to take heat from two sources, the second source being usually of fossil type (natural gas, petroleum);
- **GSHP can ensure in winter time the whole requirement** for heating, ventilation and domestic hot water for a building;
- **HP with outdoor air as heat source have the cooling performance depending on the temperature of the environment**, matter that makes in summer time in countries like Romania for example, exactly when extreme cooling is needed (July and August with temperatures above 38°C) the cooling performance for HP with atmospheric air source to be minimal;
- **The cooling performance for GSHP is not influenced by the temperature of the environment**.

If we take into account that heat pumps with renewable sources are part of a building's HVAC system (Heating-Ventilation-Air Conditioning), the following dimensionless measures can be defined:

- **A performance coefficient of the HVAC system for heating with HP** (HSPF – Heating Seasonal Performance Factor) that expresses the fraction between the annual useful heat quantity (sum of terms: the annual heat extracted from the renewable source, the caloric equivalent of the electric energy used in the compression process of the cooling cycle for the HP, the caloric equivalent of a part from the electric energy used by the circulation pumps of the HVAC system and the caloric equivalent of a part from the electric energy used by the ventilation system) and the annual quantity of electric energy used to produce useful heat (sum of terms: the total annual electric energy used by the compressor , the total annual energy used by the electrical appliances of the HVAC system: circulation pumps, electric fan coils, electric valves) all quantities are expressed in kWh/year.

- **A performance coefficient for cooling of the HVAC system with HP** (CSPF – Cooling Seasonal Performance Factor) that expresses the fraction between the annual quantity of the heat extracted from the building (heat gain to the building through the envelope area in dynamic regime, the INTERNAL LOADS generated by the building occupants – lighting, electrical cooker, computers, etc- the cooling quantity required to prepare fresh air introduced into the building through the ventilation system) and the annual quantity of electric energy used by the HVAC system for cooling the building; all quantities are expressed in kWh/year.

Compared to the above definitions we have the following situations:

- **In the HVAC systems with HP with outdoor air source case**, there is no **HSPF** for heating and preparing the domestic hot water. The reason is that HVAC systems with atmospheric air source cannot ensure the annual heating requirements only from the heat absorbed from the environment. The few situations in which a passive house, of modest dimensions, can ensure the heating, ventilation and hot water exclusively electric is by using a HP with atmospheric air source, with an additional electrical resistance HSPF ≤ 2.5 are examples at the lower limit of acceptance of the performance notion. In our opinion, HP with outdoor air source can be used for heating, with positive results, in bivalent systems for which we can calculate a HSPF only if the second heat generator is a GSHP. When the second source is a fossil fuel the HSPF does not make any sense.
- **In the HVAC system with GSHP**, for heating, ventilation and preparing the domestic hot water, the minimum value of HSPF is 2.5.
- **In the HVAC system with GSHP case** (which use open systems in water bearing layers or closed systems with vertical drilling) , the minimal value for HSPF proposed by us is 3.5.

When reffering to Romania, using the ASHRAE climatic classification for Europe (presented in the annex 1 – source Euleb) we must retain from the 4 climatic zones established by the Roumanian Standard SR 1907/97 and C107/2005 only 2 zones, identified as Csa and Dfb in annex 1; the annualy recommended energetic consumptions for buildings with high energetic efficiency are presented in annex 2, where Csa and Dfb correspond to the categories (4) Mixed and respectively (5) Cool.

Thus, we can suggest for Romania as follows :

- **Two (2) energy classes for buildings, corresponding to the 2 possible locations for the building**. The 2 energetic classes correspond to the first and second ammendaments proposed by SRG for the calculation schemes (2006 edition) of the energetic performances of the buildings (IIIrd Part – Audit and Performance Certificat of the building (MC001/3-2006)
- **Introducing the notion of energetic efficiency when reffering to HVAC installations with heat pumps** with renewable source used for the A, B and C classes for buildings situated in the high efficiency zone. The energetic

efficiency can be classified as A^+ and A^{++}, corresponding to the pairs of values sugested for the HSPF ans CSHP coefficients of minimum performance.

Thus we obtain an important **advantage**, the possibility to verify in practice the expected energetic quotation of a building using HVAC systems with renewable source, by studying the annual electricity consumption, as recorded by the monthly invoices from the local supplier. Our proposal is based on recordings made by our society between the year of 2005 and 2007, regarding a series of new buildings with HVAC installations using the ground as heat source.

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