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Heat Pumps and Heating

1. What Is a Heat Pump Designed For?

The heat contained in the ambient air, ground (soil – so-called geothermal heat) or ground or surface water cannot be utilized in common ways due to its low temperature. This so-called low-potential heat (LPT) that offers a recyclable, i.e. ecological energy source, can be transformed by means of a heat pump into heat whose temperature is high enough to facilitate its use for heating and/or for the preparation of hot service water (HSW).

2. Heat Pump Principle

The principle of the heat pump can be easily (and in a simplified way) explained with the aid of various algorithms. One of them is a mechanical algorithm: Let's imagine the construction of a stone-wall (picture 1). If a needed stone is situated above a construction site, it will roll down without our having to expend any energy on its transport. If a stone is located below the construction site, we have to transport it up, thus investing a certain amount of energy. Heat is just like stones. The distance between the stone's height and the construction site draws a parallel to the difference between the temperature of heat and the temperature of a heated room. If the heat is 'up', i.e. its temperature is greater than that of the heated area (for instance, the heat contained in a heating medium circulating in radiators), the heat 'rolls' freely over the surrounding area, thus securing its heating. If the heat is 'down', i.e. its temperature is lower than that of the heated area (for instance, the heat contained in the outdoor air or in the ground), we have to 'transfer' it up, i.e. to a higher temperature level, thus helping it to 'roll down' to the surrounding space and secure its heating. Like with stones where we have to ensure their transport upward by means of truck (i.e. the stone must be loaded, transported up, and unloaded), transport heat 'upward' must be secured by a heat pump (i.e. we have to load it, transport it up, and unload it). In either case, certain energy must be expended on transport. If we try to express the effects of both types of transport, this comparison seems to halt in places. In case of the stone, the only material we have in the construction site is only the 'transported stone'; whereas, in case of heat, the place of use contains not only 'the transported heat' but also the heat generated by the transformation of the energy expended on its transport. In fact, even the stone that is 'up' has greater (positional) energy than the stone 'down'. The expansion of its positional energy is secured by the energy expended on its transport.

The proper technical description of the heat pump should be as follows:

The principle of the heat pump (HP) is that of cooling equipment whose driving element is a compressor driven propeller by an electromotor (picture 2). In the first exchanger (evaporator), the equipment removes the heat from a lower temperature environment (of from the ambient air or from the ground), thus cooling the environment, and uses driving electric energy to supply it – in the second exchanger (condenser) – to a higher temperature environment (for instance, into heating water), thus heating the environment. Simultaneously, the heat transferred from the evaporator to the condenser is increased by the heat to which driving energy is transformed in the compressor. In other words: The heating output of the heat pump is defined by the sum of both invested energies, i.e. it is always greater than driving energy. The heating output to (electrical) input ratio gives a so-called performance factor that is therefore always greater than 1.

The total amount of heat transferred to the other environment – i.e. heating output – is contributed to by the heat taken from the first environment (that is available free of charge) by as much as 60 to 70 % and by electric energy (that has to be paid for) by as much as 30 to 40 %. Therefore, a heat pump can achieve an average of 2.5 to 3.5 kWh or more of thermal energy from 1 kWh of electric energy, which means that the heat pump's performance factor is usually 2.5 to 3.5 or even higher, provided that there are suitable conditions in place.

The transfer of heat in a heat pump is achieved by so-called working substance – a cooling agent – that permanently circulates inside the equipment and cyclically changes its form. Supplied low-potential heat (LPH) causes it to evaporate in the evaporator at the compressor's suction pressure, and the heat removed in the condenser for heating causes it to condense at the compressor's delivery pressure. The transfer and compression of vapors from the evaporator is secured by the compressor. The transfer of liquid coolant from the condenser to the evaporator is secured by an appropriate expansion (throttling) valve. The coolant must meet ecological, safety, and sanitation requirements.

The heat pump's part to which LPH is supplied is marked as the primary side of the heat pump. The part from which heat is removed for heating is marked as the heat pump's secondary side.

In addition to the above-described principle - so-called steam circulation -, heat pumps also employ other principles, yet less frequently, that are not described in this material.

Note: It should be mentioned at this point that both professional literature and scientific writing often describe the effect of heat pumps by using the term *efficiency*, which is absolutely incorrect. *Efficiency* characterizes, in general terms, the effect of transformation or transport of energy or material, is defined as the ratio of energetic production material output and input, and as such is always defined *by a value that is always less than one*. On the other hand, the *effect of the heat pump* is not described by means of all energetic flows, but it is expressed in terms of the ratio of produced heating output and the input of High-grade driving power, i.e. an indicator that is always greater than one**.** This indicator is called *performance factor*, or energetic factor, or output number, etc.

3. What Are Heat Pumps Used For?

The heat pump is used as a heat source for the following reasons:

Due to energetic and economic reasons – it reduces the consumption of energy for heating, thus diminishing operational costs of heating as well as total costs of energy in a heated building;

Due to ecological reasons – compared to other sources, it directly or indirectly markedly reduces the production of harmful emissions and saves primary energetic sources; it can also be said to secure the 'recycling' of natural heat.

4. Heat Pumps and Their Ecological Properties

The operation of each heat pump is environment-friendly. However, it is a paradox that the heat pump alone does not have to be ecological as this quality depends on a working substance – i.e. a cooling agent – that is employed by the heat pump. Some coolants – when they leak (which can never be excluded) - contribute to the disturbance of the ozone layer of the Earth and to the creation of a greenhouse effect layer. These coolants include the one marked as R 22 that is still widely used and that is on the list of HCFC coolants.

The use of the HCFC group coolants is time-limited and our legislation that regulates them is under development. Considering our accession to the EU, it is more appropriate to mention the rules governing its use as stated in the Regulation No. 2037/2000 of the European Parliament and Council from June 29, 2000 about the substances that cause the exhaustion of the ozone layer of the Earth. The following is a brief quote from the above-referenced Regulation:

Prohibition of the use of HCFC coolants:

- From 1. 1. 2004 in all new equipment.
- From 1. 1. 2010 – prohibition of the use of newly manufactured coolants for the maintenance and service of existing equipment
- From 1. 1. 2015 – prohibition of the use of equipment that employs these coolants

- Prior to December 31, 2008 – the possibility of applying the previous prohibition of the use of equipment with these coolants will be reviewed.

Regardless of the above-stated facts, the use of the heat pump – as environment-friendly equipment – with the R22 coolant, i.e. with a 'bad ecological' filling, is an anachronism. **Ecological equipment** should, in each case, **work with an environment-friendly filling**. It should also be noted that the subsidy currently provided for the installation of heat pumps by the State Environment Fund does not apply to heat pumps with the R 22 coolant.

5. How Does a Heat Pump Differ From a Regular Heat Source?

Unlike other heat sources such as electro-boilers, boilers burning gaseous, liquid or solid fuels, the heat pump features these three basic qualities.

a) The heat pump needs two energetic sources for its operation, namely suitable low-potential heat, and driving power, usually electric energy. This is why heat pumps are discussed especially when heating electric energy is dealt with.

In other words: For the heat pump to be able to heat 'on the secondary side', it must always engage in 'cooling on the primary side'. Therefore, it must always be provided with an 'environment that can be cooled', i.e. a source of LPH!

b) The heat pump's parameters – i.e. its heating output and performance factor – strongly depend on external conditions, i.e. on the temperature of low-potential heat and on the temperature of a heating medium. Whereas, these parameters become more favorable if the temperature of low-potential heat increases and if the temperature of the heating medium decreases. On the other hand, it can be claimed that the same parameters worsen if both these temperatures 'open wide' (read the characteristics provided in picture 3).

While it is usually impossible to influence the temperature of low-potential heat, we can affect the temperature of the heating medium. The low temperature of the heating medium requires the use of so-called low-temperature heating systems. Of standard heating systems, under-floor heating and wall heating offer the most suitable solutions. As a rule, they work with a medium that is 40 ^{o}C warm or even less, whereas a system with large-surface radiators usually needs a minimal temperature of 50 ^{o}C.

The above facts imply that the performance factor, being the measure of 'energetic perfection' does not depend only on the heat pump, but on the entire heating system, mainly its heating set. The dependence of the heat pump's parameters on external conditions is the most significant factor that must be taken into account when designing a heating system!

Note: **The heat pump's parameters are not defined only by its heating output. It is necessary to indicate the temperatures and temperature differences of media 'on both sides'**, otherwise a possible comparison cannot be objective.

c) The temperature of the heating medium have a maximum limited. The maximal temperature of the heating medium is usually within a range of 50 to 55 °C. The limitations are defined especially by strength aspects (The temperature of the media corresponds with the pressure of the coolant in the circuit which must not exceed a value to which the circuit is sized.) but also by energetic aspects (a performance factor decrease).

On the other hand, the temperature of the heating medium in standard heat sources is usually subject to lower limits! Appropriate measures must be taken to prevent the fall of temperature below a limit value in order to avoid both the condensation of humidity produced by combustion gases and the corrosion of the boiler (except for so-called condensation boilers).

6. The Optimal Utilization of Heat Pumps

As a rule, a heating system with a heat pump is not designed so that the heat pump covers all of required heating output at the lowest (calculation) temperature of the outside air (so-called monovalent manufacturing) because such a design would be too big and would claim huge investments. The optimal solution is a so-called bivalent heating system where a heat pump is designed to cover heating output only to a certain outside temperature, for instance, up to 0 to–5^{o}C (so-called bivalence temperature), and to be 'supported' by another heat source – for instance, an electro-boiler – at lower temperatures. Because a season with low temperatures when a greater heating output than that produced by a heat pump is required is relatively short, the other source contributes to the total consumption of heat for heating by less than 10 %. The so-designed system can achieve the optimal ratio of acquisition and operational costs, thus making it possible to save about 50 to 65 % of electric energy paid for heating.

When the bivalent solution is applied, the heat pump is usually sized to 50 to 75 % of required (calculation) heating output.

It should be pointed out in this context that the economical operation of the heat pump is conditional upon a special rate applicable to heat pumps and marked according to a new rate tariff as D55 – for households, or as C55 – for legal entities (effective from July 1, 2001). This rate restricts the time of the operation of the heat pump and of the heating system to a maximum of 22 hours a day (at the ‘low tariff’). For 2 hours a day (heat pump), its operation is blocked by a **C**ollective **R**emote **C**ontrol signal (CRC) (at the ‘high tariff’). Moreover, during the ‘low tariff’ time, it is also possible to block the operation of low rate heaters for a maximum of two hours; i.e. for instance, the operation of an electro-boiler functioning as an additional bivalent source.

Picture 4 illustrates the block scheme of a heating system with a heat pump in bivalent connection and its integration not only within a heated building but also in the entire surrounding area understood in the broadest sense of the word. It also features the ‘recycling’ of natural heat that is secured by the heat pump.

7. How Does a Heat Pump Influence the Design of a Heating System

The heat pump’s differences from standard sources and the fact that a heating system with a heat pump works similar to low rate heaters with a interrupted heating function (low rate heaters with a 4-hour daily shutdown, low rate heaters with a 2-hour daily shutdown by a CRC signal) thus raising specific requirements for the design of the heating system and for its working regime. It is also necessary to consider the layout of the heated building and if the layout cannot be modified, its possible thermally technical downsides must be eliminated by choosing an appropriate heating system solution. Compared to standard heat sources, the design of a heating system with a heat pump is therefore more demanding as far as accuracy and complexity is concerned. An improper solution could cause either discomfort in a heated building, or unnecessarily high energy intensity.

Let us briefly mention three notes regarding the designing of heating systems:

a) In order to eliminate the downside of the lower temperature of the heating medium in a heating system design, we prefer to work with a smaller working difference of the temperatures of the heating medium, which secures the greater middle temperature of the medium for the heating system. In order to transfer a certain heating output it is necessary to use a greater heating medium flow when there is a smaller working difference in temperatures. **Unlike in standard heating systems, the flow rate of the medium is usually more than doubled**. This must be taken into account when designing circular pumps, distribution lines, and the heating system alone.

b) Considering the fact that the system employs interrupted heating, it is necessary to ensure that an undesirable, unpleasant fall in temperature will not occur in a heated building during an operational break. This happens in buildings with small thermal capacity (accumulation), which is the case, for instance, in wooden structures (‘Canadian’ type houses) or in loft extensions. **If a heated building does not have necessary accumulation capacity, it must be provided by a heating system**, for instance, by under-floor heating that accumulates heat in a concrete layer. A new electric energy rate list reduces the intensity of these measures in systems with a heat pump as it cuts one break down to only 1 hour.

c) A bivalent source design causes the heat pump alone to have no or only a small output and temperature reserve for the prevalent part of the heating season (i.e. under a bivalence temperature). Therefore, it is necessary to apply an **operational mode without thermal damping** (However, certain damping is always introduced in the system by heating blocking by means of the CRC signal.) at lower outside temperatures (Temperatures that approximate and/or are lower than a bivalence temperature.). The application of damping results in the inability to achieve a required room temperature and the desired comfort of the environment. As a rule, the errors causing this situation are wrongly attributed to the insufficient sizing of the heating system. Fast fire-up to a required temperature can then be accomplished only when an additional bivalent source is connected at the same time, which is not energetically reasonable.

The respective connections are shown in the daily characteristics of a heated building in picture 5. This information features the course of temperatures in a heated building during the day at a bivalence temperature (-2^{o}C), depending on other marginal conditions.

Picture 5a clearly implies that if operation takes place under the above-described conditions and 'without damping', the source still maintains a certain time reserve even at the bivalence temperature (operation hours: 21.2 hours). This is due to the fact that the source keeps a certain output reserve within a certain time interval (at higher outside temperatures). Picture 5b implies that selected 'night damping' reduces energy consumption from 88.0 to 80.5 kWh, i.e. nearly by 9 %, yet it brings about a simultaneous decrease in not only the middle but also the highest temperature inside a building of about 2°C. Under such conditions the source – the heat pump alone – cannot secure a required temperature inside the building!!! Picture 5c implies that a required temperature can be achieved only when attaching an additional bivalent source (only 50 % of its output is considered) that secures the output and capacity reserve necessary for the coverage of immediate losses as well as a necessary increase in room temperature. An increase in energy as opposed to the no-damping condition is quite obvious – from 88.0 to 147.8 kWh, i.e. more than 50 %.

8. Heat Pump and Heating System Cooperation In Existing Buildings

In the majority of existing family houses (built ten and more years ago), which are usually provided with so-called central heating burning solid fuel, heating systems used to be designed for a medium heating temperature of about 65 to 70^{o}C and higher, whereas the heating medium engaged in so-called 'gravitation' circulation. Many of those houses underwent further development and a solid fuel boiler was replaced with low-rate heater, i.e. an electro-boiler, or a natural gas boiler; and the gravitation circulation system was replaced by forced circulation – i.e. the distribution lines were fitted with a circular pump.

It appears that the majority of these buildings have a source – i.e. a boiler (regardless of whether it burns solid duel, natural gas, or whether it is an electro-boiler) – and a heating system that are overdesigned, which is due to the fact - amongst others – that their designs calculated in a so-called fire-up overplus that accelerated the firing process under the conditions of markedly interrupted heating (Firing a boiler after coming home from work or school.). The overdesign of the heating system is usually so substantial that the heating of a building can be easily secured even at lower temperatures that use utilized by bivalent systems with a heat pump and during operation without thermal damping. This is further aided by the distribution lines that are amply dimensioned to 'gravity' and that make it quite easy to process larger volumes of heating medium, as those are required by this type of system.

Although each specific case requires an expert assessment to be carried out by a heating engineer familiar with the heat pump issues, it can be assumed with regard to most installations that a heat pump can be employed in existing buildings in connection with their current heating system that is to be slightly modified, if need be (for instance, by enlarging the heating surfaces in a critical point or by placing a low-rate heating convector into a critical room and by controlling the same in a 'bivalent' way). This argument is supported by numerous heat pump installations completed in existing buildings.

9. Suitable Sources of Low-Potential Heat

Heat pumps are usually divided or marked according to the applied source of low-potential heat. The basic sources include:

a) **Outdoor air** – suitable for **'air-water' pumps**
The heat contained in the air can be used directly in a heat pump in which case the design of the evaporator allows for the direct flow of the outside air.

This source of low-potential heat is the most easily accessible, its capacity is practically unlimited, and it can be said to be the most ecological because the heat taken from the surrounding environment is returned to the same environment thanks to the thermal loss of buildings. Considering that the temperature of the air varies substantially during the heating season, the changes of this temperature and the above-described principles are connected with changes in the heat pump's heating output and performance factor. From the point of view of the all-year consumption of energy for heating, the deteriorated parameters of the heat pump at low outside temperatures are offset with their better parameters during warmer seasons.

The fact that the heat pump's parameters deteriorate at the lowest temperatures is often mentioned as the downside of this type of pumps. However, the worsening of parameters in up-to-date types of heat pumps is not so bad that it would prevent their use; the pumps can operate at an ambient temperature of –20 to–25°C. Taking into account the following paragraph, high-quality pumps 'air-water' and 'earth-water' are fully comparable as to their energetic parameters. The real advantage of these heat pumps is that the costs of their acquisition are lower than those of the 'earth-water' heat pumps (as their acquisition costs must be added with a ground collector).

b) **Geothermal heat** – suitable for the **'earth-water' pumps**

The heat contained in the ground, i.e. in a solid substance, is usually used indirectly; it is obtained in an appropriate heat exchanger (collector) and the transferred through a circulation circuit into a heat pump evaporator by means of heat-carrying liquid. The applied liquid is non-freezing and ecologically safe. The circulation of the heat-carrying liquid is secured by a circular pump. The circulated liquid is cooled in the heat pump evaporator to be reheated in the exchanger.

Heat is obtained in an exchanger made of plastic tubes that is seated:

- Either in a deep hole or holes that are as much as 150 m deep
  (suitable for more extensive procedures)
- Or in a surface or dugout collector (placed in a depth of 1.5 to 2 m)
  (suitable for less demanding procedures)

The main advantage of these pumps is often said to consist of the fact that they take heat from the ground whose temperature is, sufficiently deep under the surface, substantially greater (10°C) than the temperature of the ambient air, especially during the coldest season. This statement is not objective. The heat from the ground is removed in an entirely different way than the heat from the air. The removal of the heat from the ground is always connected with the cooling of the massif surrounding a collector; therefore, the temperature in the immediate vicinity of the collector (that also defines the temperature of heat-carrying liquid and of low-potential heat) is always markedly lower than the temperature of intact massif. The temperature tends to fall below zero, thus causing the freezing through of the massif around the collector. The temperature of the low-potential heat taken from the ground is thus greater than the temperature of the ambient air only for a short period during the heating season. On the contrary, the medium temperature of the air during the heating season is higher than the temperature of the low-potential heat taken from the ground. Meanwhile, a collector placed in a hole is much more convenient (but also more expensive) than a surface or dugout collector.

c) **Ground (well) water** – appropriate for the **'water-water' pumps**
The heat contained in well water can be, subject to specific conditions, used directly in a heat pump, i.e. the water is led directly to a heat pump evaporator. This is the case when the water has suitable composition, is clean enough, maintains a required temperature of at least 8 °C all of the year, and is available in a sufficient amount.

Water cooled in a heat pump must not flow back directly into a consumption well! The well would cool off quickly and the source of low-potential heat would become insufficient. It is not advisable to discharge the cooled water into sewerage or watercourses because it turns ecologically more valuable ground water into less valuable surface water. The most appropriate solution is to return this water to the other (absorbing) well that is situated far enough and whose position allows – if possible – for the flow of the ground water from the absorption well to the consumption well. During its flow from the absorption well to the consumption well, the water warms up in the ground, thus preventing the loss of ground water.

Of all sources of low-potential heat, ground water has the highest temperature during the heating season; therefore, the energetic effect of the 'water-water' pumps is optimal. However, this source is rarely easily available.

d) **Surface water** – usually used for nonstandard pumps or solutions
Surface water that should be used as a low-potential heat source for a heat pump must meet the same requirements as ground water (i.e. as to its composition, purity and quantity). The biggest problems concern not only its purity, but mainly its temperature that falls even below 4 °C

during the winter; i.e. below a temperature level that is utilizable by the common types of pumps, in water streams that are not heated by waste heat produced by industrial plants. ‘Creek-behind-our-house’ sources can present two problems: low temperature and a small flow rate.

Provided that the flow rate of surface water is sufficient and its use is desirable even at lower temperatures, a nonstandard solution must be employed, for instance, the transfer of heat through nonfreezing liquid with another exchanger immersed in a water stream (This worsens the energetic effect.), of by means of a pump with a special evaporator immersed in a water stream (The evaporator design prevents possible ice formation from destroying the same.).

Respective legislative regulations must be observed whichever solution is applied.

e) **Solar energy**
This type of energy is mentioned only for the sake of completeness. If used actively by means of so-called solar collectors (SC), solar energy as an independent source of low-potential heat for heat pumps is absolutely insufficient. Therefore, it has to be used in combination with another low-potential heat source, which presents higher investment costs that are not proportionate to marginally increased energetic effect. This is why such a solution is economically ineffective.

Naturally, this does not apply to the passive use of solar energy that is secured by an architectural layout and by the construction manufacturing of a heated building, i.e. not by the design of the heating system. The term ‘passive use of solar energy’ means the use of greenhouse effect for the heating of suitably designed interior building structures by means of which the interiors of the same building can be heated as well.

The basic energetic comparisons of the various combinations of a heat pump and a solar collector are given (without detailed comments) in picture 6.

f) **Waste heat**
Waste heat that is produced mainly in a variety of technological processes can, in many cases, provide a suitable source of low-potential heat. However, it rarely finds substantial applications in the heating of family houses. Its use is mainly connected with the heating of industrial premises and workshops. The designs of its use must be adapted to specific conditions.

g) **Absorbers of energy from the ambient environment** – suitable for **the ‘earth-water’ pumps**
Absorbers are mentioned only for the sake of completeness. They are large-surface exchangers that utilize both energy contained in the surrounding environment – air, humidity, and in rain -, and solar energy. The energy from the surrounding environment is thus obtained by means of flowing, leading, and heat radiation. The absorbers can be designed either as equipment without larger accumulation or as equipment with larger accumulative capacity. They either form a direct part of a building structure (for instance, energetic roofs and pre-built energetic walls), or are entirely independent (for instance, energetic fences, energetic walls, ‘decorative’ energetic stars, fans, boundaries, etc.), or they form a part of a special-purpose structure (for instance, noise barriers and springing walls, garage walls, etc.). They work either separately, or in connection with a huge, underground heat accumulator that can also function as a well for ground-contained heat.

The absorbers combine, in a seemingly efficient way, the possibility to obtain low-potential heat from both the ambient environment and solar energy. However, it should be noted that the transfer of heat from an absorber to a heat pump is always indirect. So is the taking of low-potential heat from the ground. This method is thus connected with two heat transfers. Unlike a heat pump that takes low-potential heat from the air, the primary side of a heat pump used in this application features a ‘thermal loss’ of at least 5 or more °C, which is connected with the worsening of performance factor and with an increase in a minimal outside temperature at which the heat pump can still be operable. The concentration of nonfreezing liquid must always be greater than when taking heat from the ground (in which case concentration is usually selected for a minimum temperature of -15 °C) because it must be designed for an extreme outside air temperature (as a rule, it is -25 °C), considering all other related adverse impacts.

The use of a heat pump that takes low-potential heat directly from the air will therefore present a more effective option with regard to energetic aspects. Meanwhile, we can afford to omit economic issues connected with acquisition costs as well as technical issues connected with the condensation and freezing out of air humidity on an absorber at low air temperatures.

This solution is a product of its time when the high-quality ‘air-water’ pumps were not available.

10. Differences Between the Individual Manufacturing Versions of Heat Pumps

The heat pumps discussed in the previous paragraph do not feature principal differences on their secondary side. The primary side is identical on ‘earth-water’ and ‘water-water’ heat pumps. In both of these heat pumps, the supply of low-potential heat is secured by nonfreezing liquid or water. Therefore, these heat pumps differ only as to the extent of measures preventing the possible freezing of an evaporator.

Quite different than these two types are the ‘air-water’ heat pumps, which is due to the fact that their supply of low-potential heat is mediated by the air whose temperature changes throughout the year. The cooling of the air on the evaporator is accompanied with the condensation of air humidity. At higher air temperatures, the condensate flows away freely (The discharge of the condensate must be provided!), yet at lower temperatures, the condensate freezes on the surface of an exchanger and forms ice. The ice must be removed periodically – melting away – to prevent the failures of the evaporator and of the entire heat pump. The melting is carried out in various ways. Let’s mention that some of those methods utilize the ‘reversing’ of the heat pump’s operation during which the function of both exchangers is swapped. If this type of melting is applied, heat is taken from a heated structure and produced heat is then used to heat and melt the evaporator. This aspect must be taken into account when designing a heating system.

11. The Effect of the Development of Components on Heat Pump Parameters and Utility Properties

The main components that principally affect the heat pump’s parameters and utility properties are a compressor, applied cooling agent, heat exchangers (i.e. an evaporator and a condenser), ventilators (used with the ‘air-water’ heat pumps) and a control system.

Plate-type heat exchangers and microprocessor control systems that began to find broad applications in the last decade bring significant benefits to the field of cooling equipment and heat pumps. Low-noise, high-capacity ventilators allow for the installation of ‘air-water’ heat pumps even in badly exposed residential zones. However, a true generation leap in the area of heat pumps came along with the application of special ‘SCROLL’ spiral compressors (drawing 7) in combination with low-temperature, environment-friendly coolants.

It has been mentioned earlier in this information that the parameters of heat pumps markedly depend on external working conditions and that both heating output and performance factor deteriorate if the temperature of the heating medium increases and if the temperature of the low-potential heat decreases. When these temperatures depart from each other, the compressor has to overcome a greater *temperature difference*, or rather an *equivalent pressure difference and a greater compression ratio*. The further worsening of the heat pump’s parameters is caused by a change in the thermodynamic properties of a coolant occurring at the above-described change of temperatures, but mainly – which is the case with standard piston compressors – by a decrease in the volume, or rather transport efficiency of a compressor accompanied with an increase in a compression ratio.

The generation leap introduced by the spiral compressors consists in the fact that these compressors work with nearly 100% volume efficiency. Therefore, their parameters are affected only by the thermodynamic properties of a coolant. If the temperatures begin to depart each other, even these compressors feature a decrease in heating output and performance factor, yet this decrease is pronouncedly lower than that observed in piston compressors.

It ensues from the above that if suitable coolants are used, it is a real challenge to employ for a heat pump even those sources of low-potential heat that have been considered unusable or usable with strict limitations. This applies especially to the ambient air whose utilization at temperatures lower than -5 to -10°C used to be considered ineffective. However, if used in combination with a spiral compressor, the limits of its efficiency move further to a temperature of -20°C and less. Given that periods with such extreme temperatures are relatively short in our climatic conditions, they can be easily overcome if a bivalent heat pump connection is applied.

The spiral compressors also have other great features, the main of which are:

- Markedly longer service life (reportedly up to 2.5 x longer) thanks to the smaller number of mobile components and thanks to a different mode of movement;
- Lower current rush at startups because the compressor is started as 'unloaded';
- Lower noise levels.

12. The Effects of Heat Pumps on the Consumption of Energy for Heating

The need for heat for heating and the effect of the heat pump on the consumption of energy for heating is best shown in a diagram of the frequency of temperatures during the year. Such a diagram is provided for a certain calculation temperature - i.e. for a certain place – presented in picture 8a. The diagram is based on a characteristic curve of the frequency of temperatures, i.e. a line of 'external temperatures'. A deliberate temperature is assigned with the number of days during the year when an average temperature is lower than a given temperature. The temperature that defines the beginning of the heating season is then assigned with the number of days during which the heating season lasts, or rather with the length of the heating season.

This diagram can show all relevant energetic relations connected with heating. If you enter the required temperature of a heated area – i.e. a line of 'internal temperatures' - into the diagram between the vertical lines characterizing the length of the heating seasons (in picture 8a, this value is 22^{o}C), the area between the lines of 'internal' and 'external' temperatures and both vertical lines is proportionate to the heat needed for heating. The vertical abscissas between the lines of the 'internal and 'external' temperatures are proportionate to a required heating output and the ratio of their lengths equals the ratio of required heating outputs at varying external temperatures.

Such a diagram shown in picture 8b images the effect of the 'earth-water' heat pump. This effect is described with a full line characterizing the relative input of the driving power of the applied heat pump. The line divides the area of the need for heat. High-grade (concentrated) driving power covers only a part of the need for heat for heating. The prevalent part is covered by natural heat; i.e. by low-potential heat that is required for the operation of the heat pump. This heat represents the saving of driving power for heating. The diagram further shows a bivalence temperature; i.e. a temperature to which a required heating output is covered only by a heat pump. At temperatures below this level (approximately 25 says a year), the heat pump is aided by a bivalent source; for instance, an electro-boiler. Its relative input is characterized by the other line (that deflects the first line). The other line also divides the area of the need for heat. The ratio of the individual areas to the total area expresses the relative energetic consumption of 'high-grade' energy and relative energy savings, or rather the relative consumption of 'natural' energy.

The diagram shown in picture 8c images the effect of the 'air-water' heat pump. The description corresponds with the previous picture. The diagram includes all important facts that are characteristic for this type of heat pump:

- If temperature drops below a certain limit value (in this case about 2^{o}C), the energy intensity of the heat pump increases (a jump in the characteristics). This increase is required for the melting of ice that forms on the evaporator when removing the heat from the air. The limit temperature and the extent of the jump depend on the employed type of evaporator melting.
- The 'air-water' heat pump has a higher bivalence temperature than the 'earth-water' heat pump with the same compressor (subject to the conditions stated below).
- If temperature drops below a bivalence temperature, the amount of the heat covered by the heat pump is decreased.

Picture 8d provides a comparison of the energetic relations of heat pumps manufactured as per pictures 8b and 8c. Their detailed comparison implies that the energy intensity of high-quality heat pumps of both versions is fully comparable. If the 'disadvantage' of the 'air-water' heat pumps is their worse effect at the lowest temperatures, then the 'downside' of the 'earth-water' heat pumps can be seen in their worse effect if a higher temperature period lasts too long. Meanwhile, the disadvantage of the 'air-water' heat pumps can be eliminated, in most cases, by using a frequency converter and by increasing the revolutions and capacity of the compressor at lower temperatures (the area characterizing the 'extra' consumption of energy is then diminished markedly).

In order to better illustrate the above-stated facts it has to be added that the above-described comparison applied simplified and advantageous preconditions for the 'earth-water' heat pumps for which parameter changes were not considered during the heating season (However, such changes take place, even though to a smaller extent, as they do in the ‘air-water’ heat pumps.).

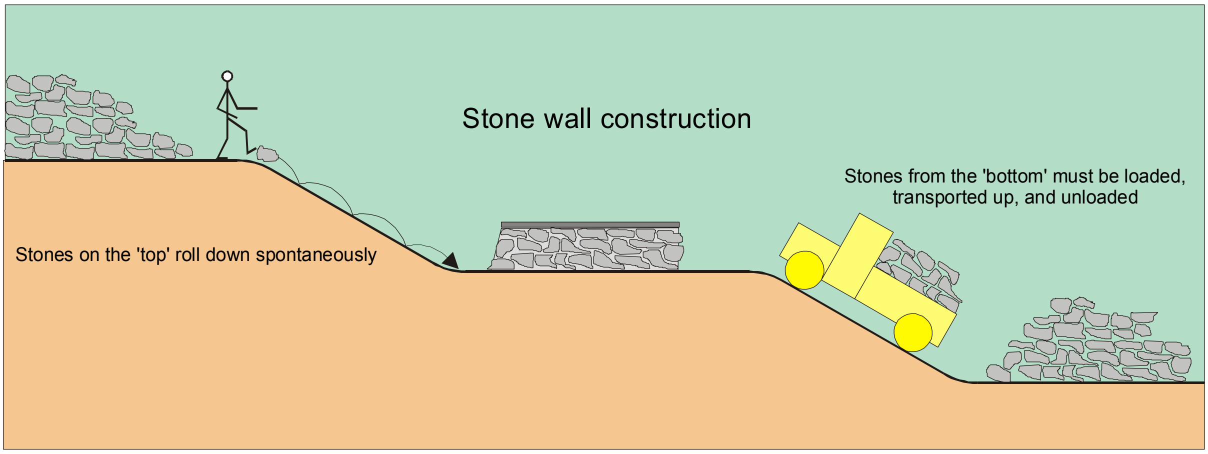
Obviously, the energetic relations described in the previous pictures can be computer- processed in absolutely exact terms if marginal conditions, chosen manufacturing, and the type of heat pump are selected. The obtained results can then also be used for the processing of price relations, i.e. for expressing costs of energy needed for heating, or rather for expressing the savings achieved by the use of a heat pump.

Let’s note with regard to the previous facts that a reduction in the energy intensity of a structure is not accompanied with an equivalent reduction in costs of energy. This is due to the fact that energy fees include so-called fixed monthly charges as well as due to the fact that in addition to these requirements in question, each heated building and its occupants have also other, not negligible energy requirements (HSW preparation, cooking, laundry washing, refrigerator, freezer, dishwasher, lighting, audiovisual equipment, etc.).

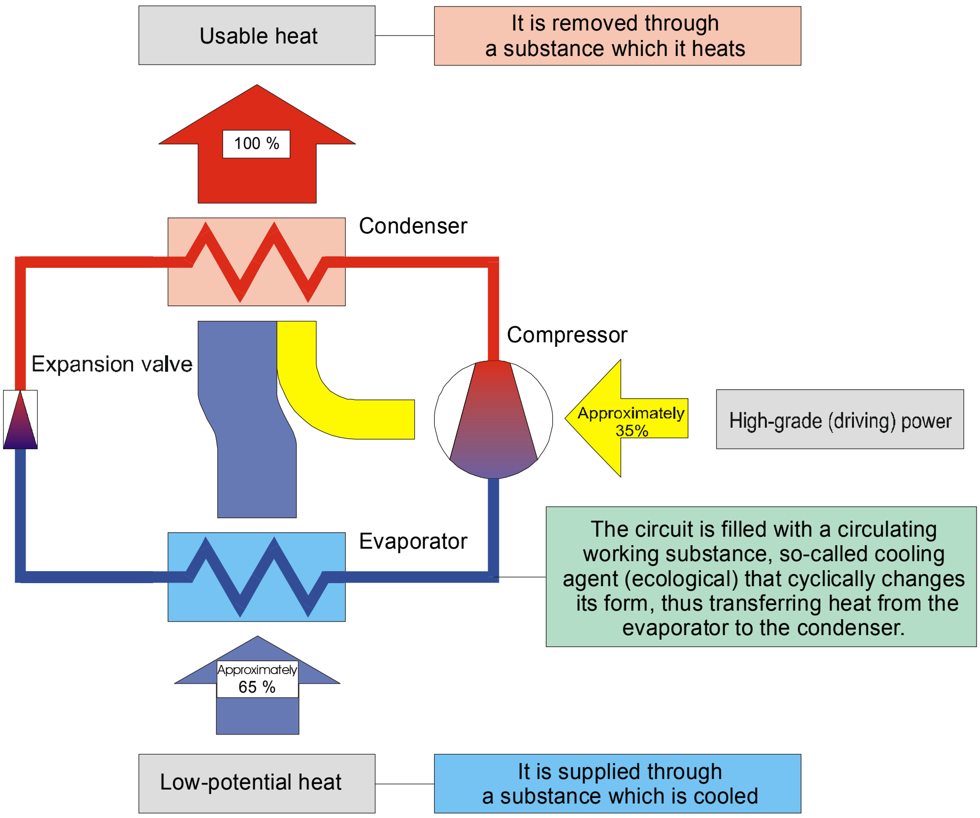
Analogy of mechanical and thermal energy

Temperature is to thermal energy (heat) what height,
is to mechanical energy (stones)

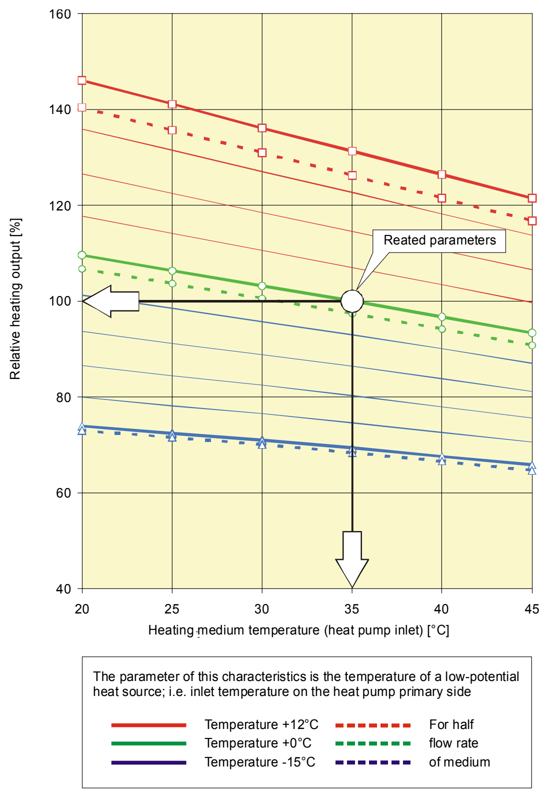
Heat can spontaneously transfer only from a substance with a higher temperature to a substance with a lower temperature
(Stones can roll only from 'top to bottom')

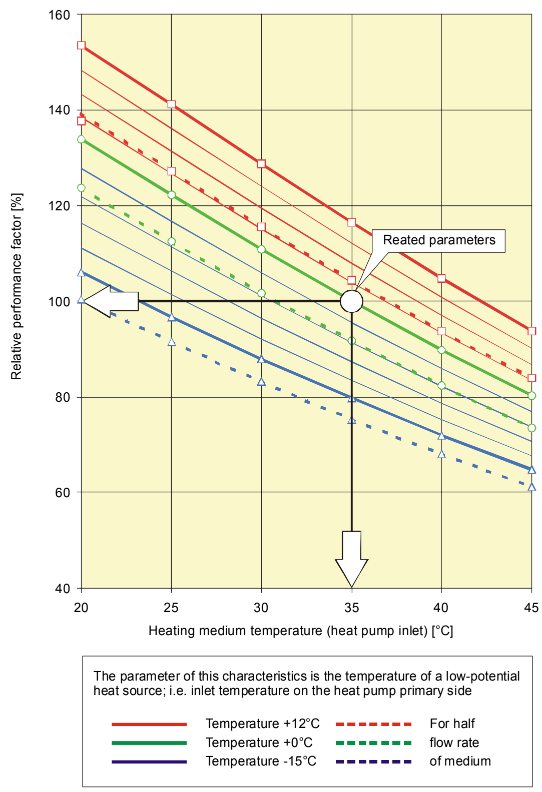


Picture 1 Heat pump principle mechanical algorithm

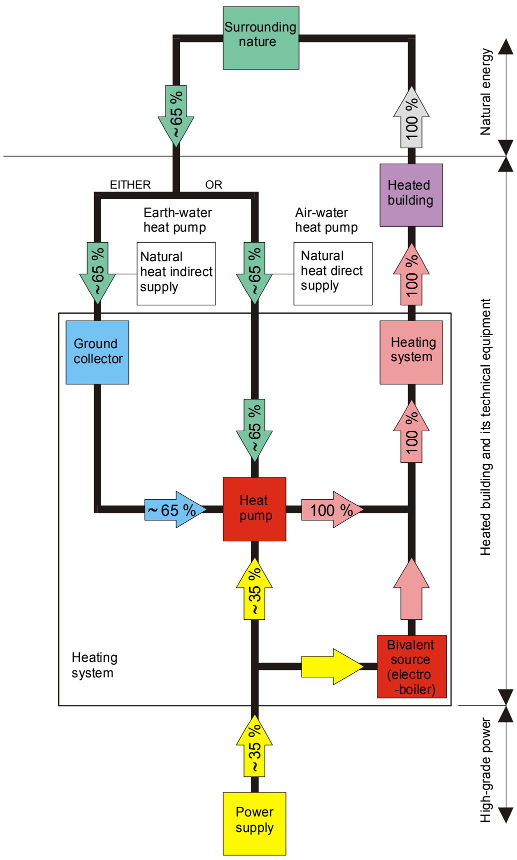


Picture 2 Heat pump principle real scheme

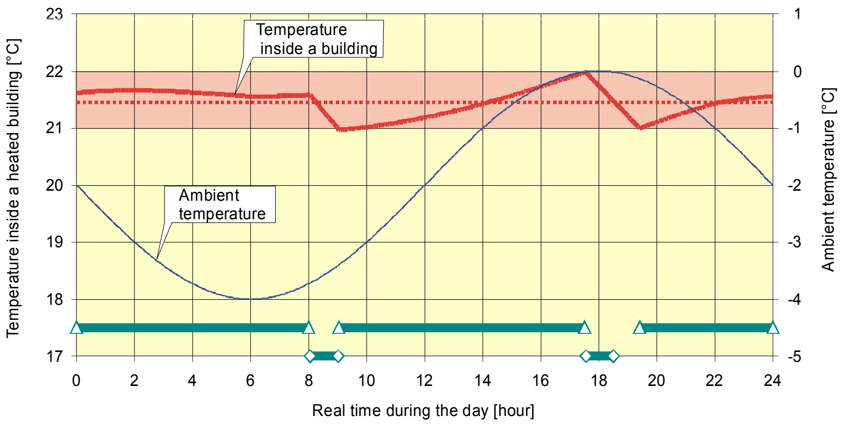




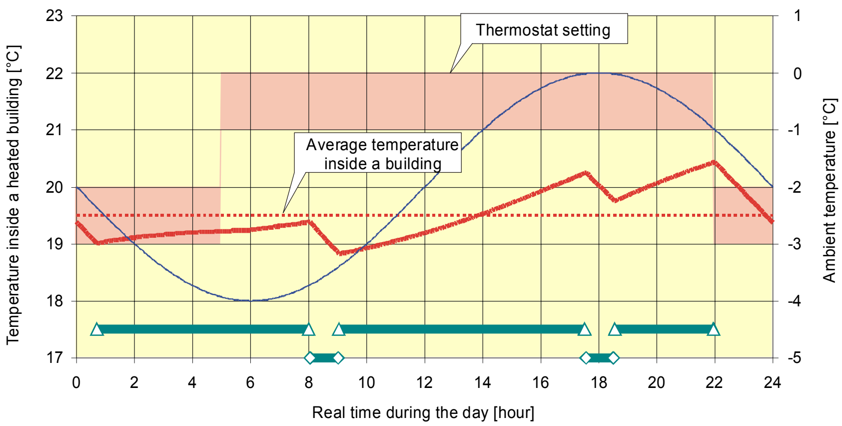
Picture 3 Heat pump characteristics



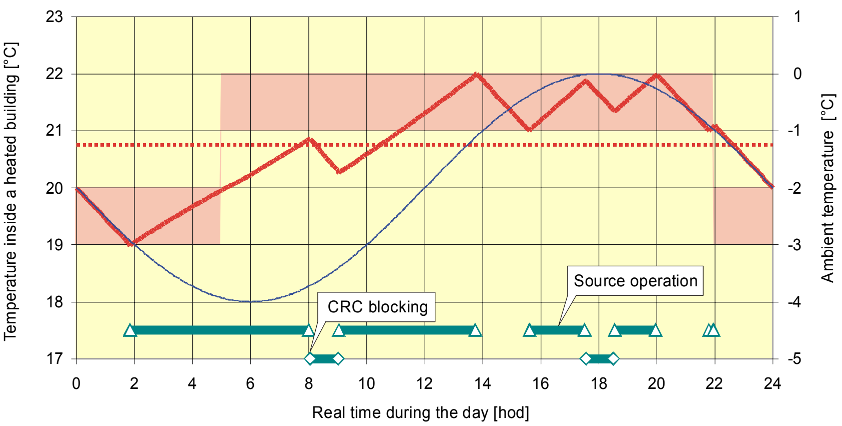
Picture 4 Block scheme of a bivalent heating system with a heat pump



Without damping: PD = 21,2 H/D, ti_{str} = 21,5 °C, Q_t = 306 kWh/D, N_z = 88,0 kWh/D, TC



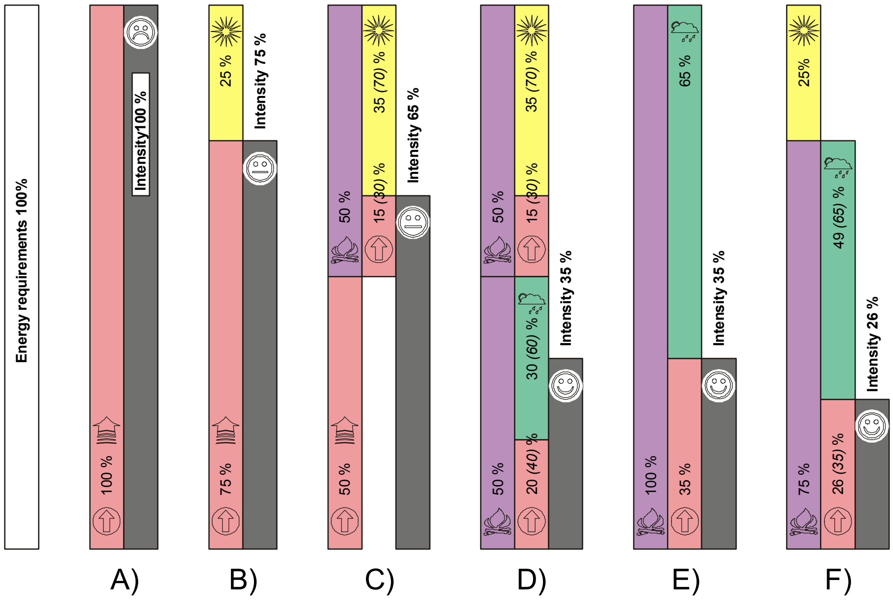
With damping: PD = 19,3 H/D, ti_{str} = 19,5 °C, Q_t = 281 kWh/D, N_z = 80,5 kWh/D, TC



With damping: PD = 14,6 H/D, ti_{str} = 20,8 °C, Q_t = 298 kWh/D, N_z = 148 kWh/D, TC+0,5EK

Picture 5 Heated building characteristics - the effect of thermal damping at a bivalence temperature
The development of temperatures in a heated building during the day depending on variable marginal conditions

Explanation:
PD - Heat pump working hours — Hour/Day
ti_{str} - Average temperature in a heated building — °C
Q_t - Need for heat for heating — kWh/Day
N_z - Bivalent source energy consumption (heat pump + electro-boiler) kWh/Day
TC - Heat pump in operation
EK - Electro-boiler in operation (with an indicated output ratio)



Explanations:
- Heat obtained directly from electric energy
- Heat supplied by a heat pump
- Heat from solar energy
- Low-potential heat (LPH)(natural)
- Electro-boiler (EB) and/or heat pump (HP) power input

Heating system	Energy requirements coveragee %				EI %
	EB	SC	HP+LPH	HP+SC	
A) Electric low-rate heater (EH) electro-boiler (EB)	100				100
B) Pure solar solar collectors (SC)	75	25			75
C) SC and HP combination without further LPH	50			50	65
D) SC and HP combination with further LPH			50	50	35
E) Independent heat pump (HP)			100		35
F) SC and HP combination independent systems		25	75		26

Picture 6 Reduction of the energy intensity (EI) of electric heating by various combinations of 'solar heat pump' systems

Copeland

SCROLL compressor

Two functional parts spirals
- fixed - blue
- mobile - red

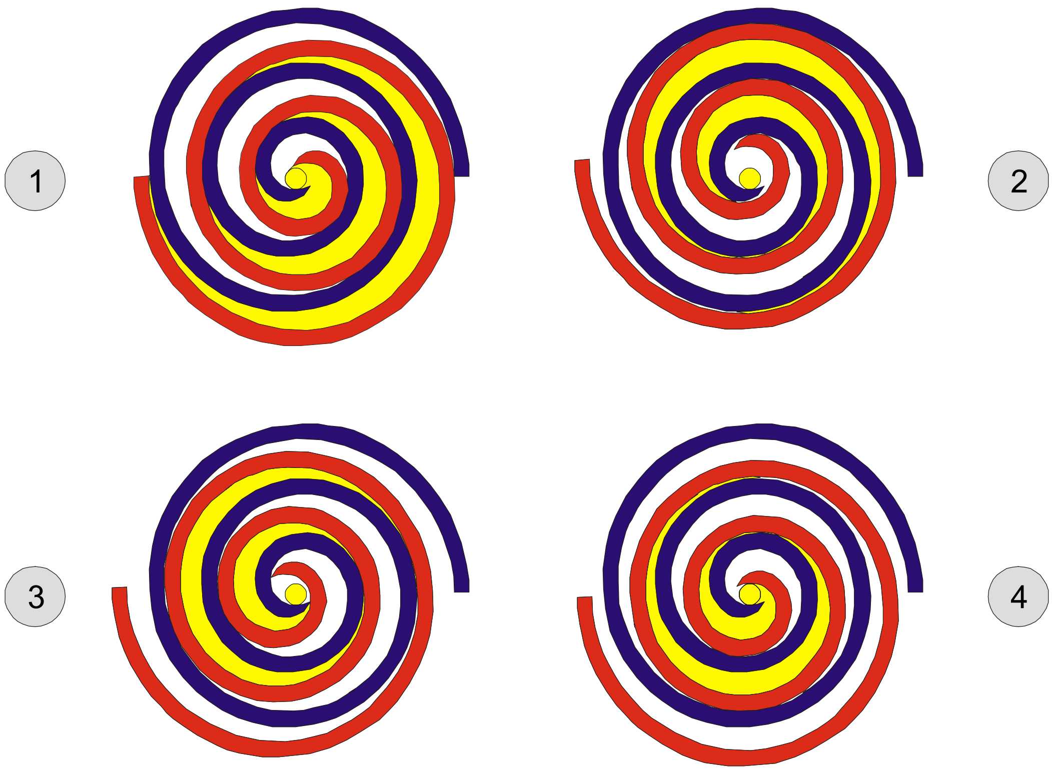
Mode of motion
- rolling - no rotation

Spiral sealing I
- radial and axial by means of direct contact without sealing, accomplished by micron-based accuracy of production

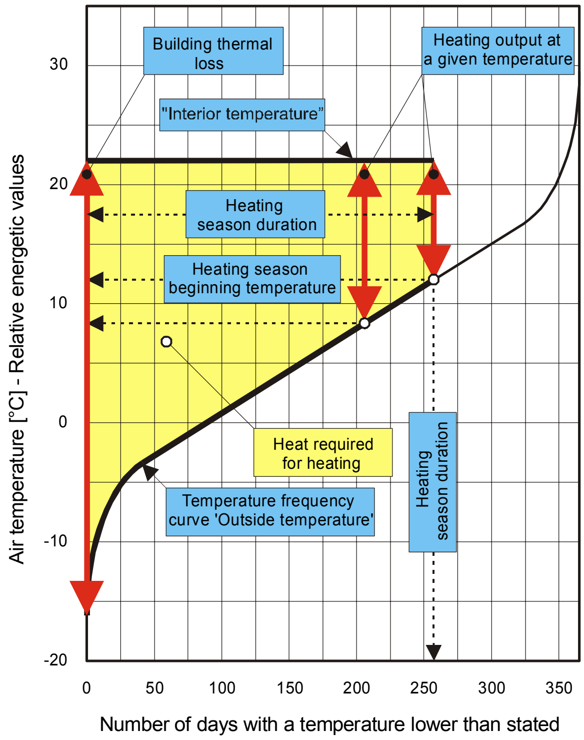
Working sides
- suction - on the periphery
- delivery in the middle

Course of compression
- the volume of steam marked with a yellow sickle (on one side only) moves from the periphery to the center and diminishes

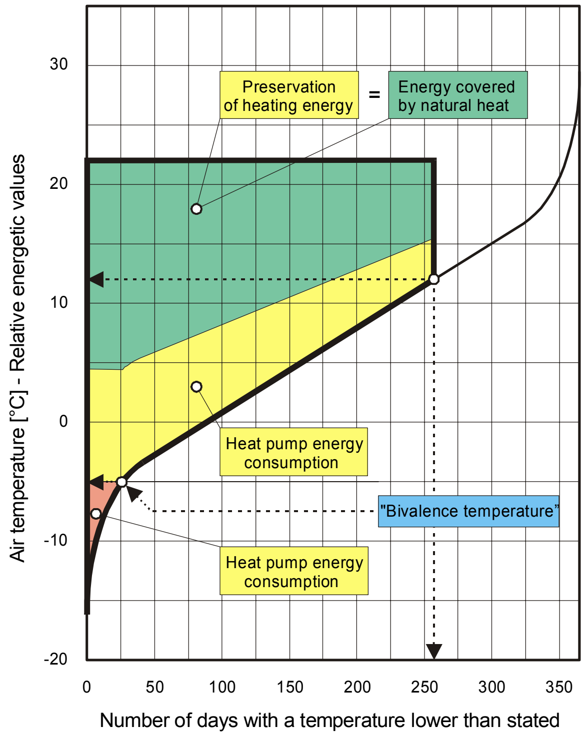
Various operating stages of the SCROLL compressor



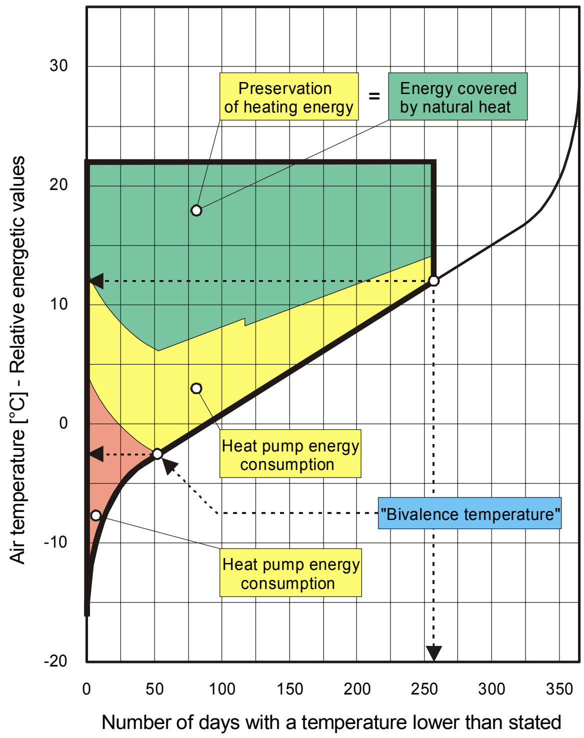
Picture 7 SCROLL spiral compressor functional part scheme



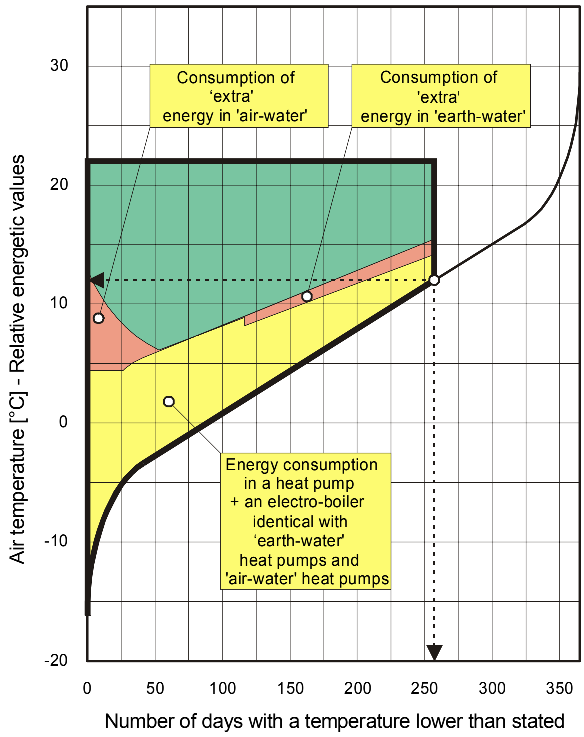
Picture 8a Heat required for heating
Heating season parameters - Heating output relations



Picture 8b Relations between energy requirement and consumption in 'earth-water' heat pumps



Picture 8c Relations between energy requirement and consumption in 'air-water' heat pumps



Picture 8d Relations between energy requirement and consumption comparisons in 'air-water'

Picture 8 Energetic balance of a heated building in a diagram of temperature frequency during a year