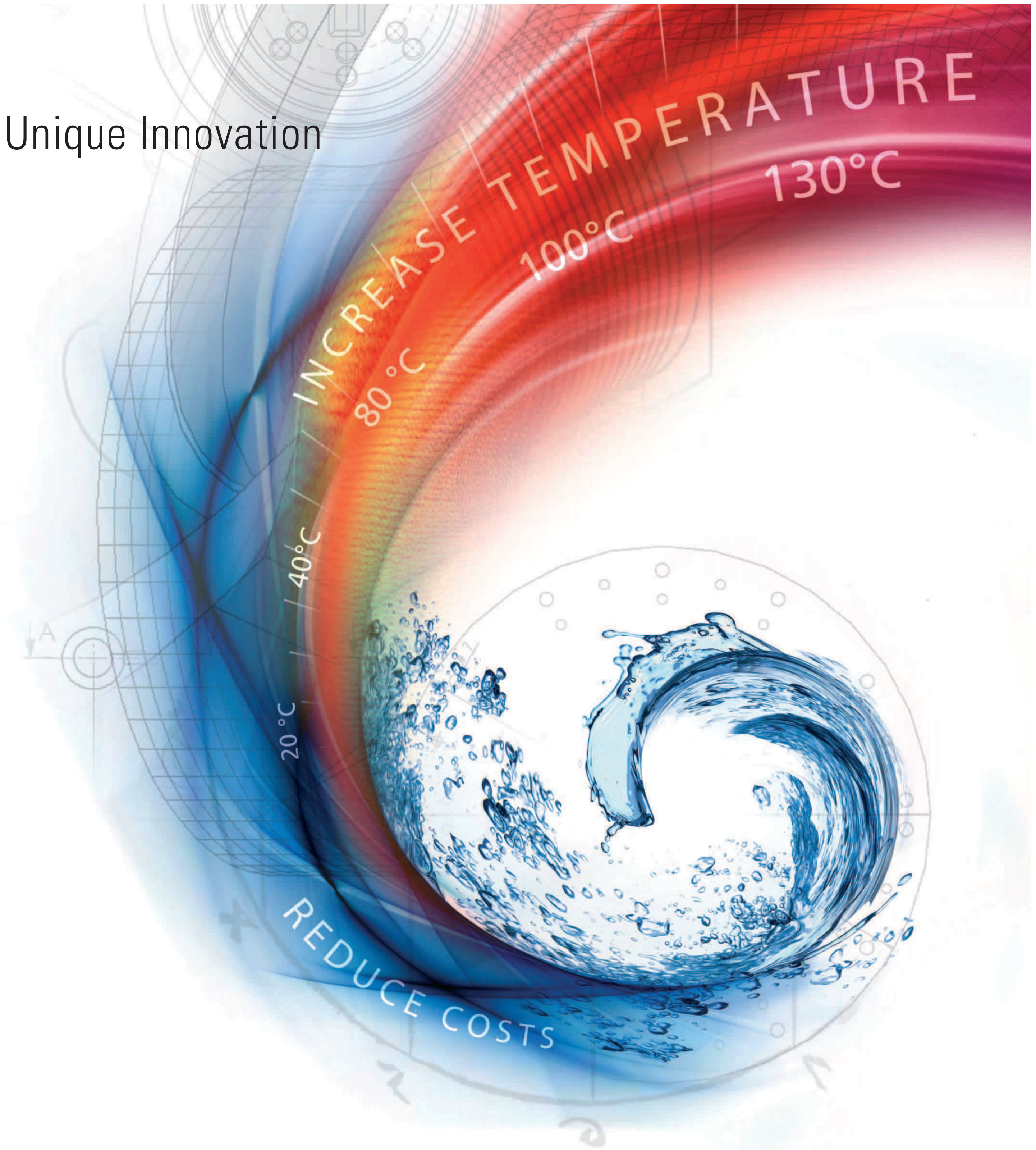
Unique Innovation



High-Temperature Large Scale Heat Pumps for Industrial Use

thermea. Energiesysteme

Contents

thermea. High-Temperature Heat Pumps

Thermea Plc. develops and manufactures high performance large scale high temperature heat pumps with carbon dioxide as working fluid. Our machines are designed for the recovery of industrial waste heat of low temperatures.

Arguments at One Glance:

Reducing costs
- > Waste heat utilisation
- > Unburden the cooling tower
- > Low operating costs
- > No exhaust-gas system required
- > No fuel storage
- > Emissions trading

Improve your image
- > Application of cutting-edge heat technology
- > Environmental management
- > Future-orientated investment

Preserve the environment
- > Saving primary energy
- > No exhaust-/heat emission
- > CO_2 –reduction
- > Natural working mediums
- > Preserving resources

Many of the arguments mentioned above apply for heat pumps in general. The section "Special Features of Heat Pumps with Carbon Dioxide" explains the thermodynamic highlights of our product.

What distinguishes the thermea. heat pump from similar currently available products?

Unique selling points:

- > Natural, environmentally friendly working fluid CO_2 (see additional information)
- > High heat capacity up to **4.0 MW**
- > Potential flowing temperatures up to **130 °C**
- > Maximum energetic efficiency/ **Coefficient of Performance**

thermea.SteamGeneration (SG)

Can the following conditions be found in your company?

> Is steam required?
  Water vapour e.g. 1.5 bar, 110 °C, several MW, ≥ 5,000 h/a

> Is a heat source e.g. in form of waste heat available?
  Industrial waste heat (see information sheet „Industrial Waste Heat Potential")

Then a Heat Pump Application is profitable!

The industry requires process heat which is generated through the application of fossil fuels. After the course of operation is completed, waste heat normally remains as a waste product which is discharged into the environment by cooling towers.

Please consider that:

The heat which is dissipated through the cooling tower has been expensively created and energy prices continue to rise!
Heat dissipation causes hardware costs (re-cooling system) as well as substantial operating costs (electrical energy, fresh water, staff, maintenance, servicing).

Our offer to you:

We regain your waste heat, also with the help of partners as a contracting model, if you wish.

Thermea. has developed a sensible solution to generate water vapour within a multi-stage process. The proportion of energy which is provided by the heat pumps is thereby 85 %.

Thus, various industrial applications in which the appliance of a heat pump was technically or economically not possible before, can now be opened up.

Heat pumps give you the opportunity to create valuable reusable heat as low waste heat temperature levels are increased to the desired effective temperature with the input of energy.
However, the industrial use of heat pumps is restricted as many technological processes require the application of vapour steam. State-of-the-art heat pumps provide warm/hot water, though they are not designed to generate energetically efficient water vapour at an utilizable temperature level. This is due to the fact that water vapour generation (with currently available technology) first heats the water up to boiling temperature (supply of sensitive heat) until the vaporization is eventually carried out through further energy input at a high temperature level (supply of latent heat).
The primarily latent part of the heat reduces the efficiency of the heat pump under atmospheric pressure, higher pressure and/or higher temperatures until it finally reaches economic inefficiency. A further restraint is the re-setting of technological processes from the operation using vapour steam to warm/hot water.
This re-setting, especially with combined systems, does not justify the required effort and expense.

Many commercially available manufacturing machines, however, assume that there is a water vapour supply. That is the reason why we have committed ourselves to the task of designing an innovative solution for the generation of water vapour through the use of heat pumps.

thermea.SG - Steam Generation from Waste Heat

The process

Common industrial waste heat flows (e.g. in the form of sewage, cooling water or exhaust air) with temperatures of about 30 °C are suitable for this process. The steam generation is carried out in two process steps. Within the first step, hot water (t < 100 °C) is prepared by a heat pump.
As water is not vaporized at barometric pressure, the desired low-pressure for vaporization is produced by a vapour steam compressor (e.g. water with 70 °C vaporizes at a pressure of around 0.32 bar). The developing steam is then aspirated from the compressor which compresses it to the desired pressure level. The efficiency of the process depends strongly upon the steam pressure, therefore it is recommended to opt for steam pressure which is just as high as effectively necessary.

Profitability

The profitability of steam generation from waste heat predominantly depends upon investment and energy delivery costs. Investment costs for heat pumps are higher opposed to those of conventional steam generators, and thus have to be refinanced through energy savings. Depending on the size of the plant and the desired steam parameter, the following figures can be achieved:

Performance factor of the entire process:	≥ 2.8 (at 1.5 bar saturated vapour)
Investment costs:	200…300 €/kW

Conventional Steam Boiler		
Heat capacity	5,0	MW
Operating hours	7.000	h/a
Annual heat quantity for stem generation	35.000	MWh/a
Heat price= fuel price *(Hs/Hi)/η generation	49	€/MWh
Annual steam costs	1.715.000	€/a

HP-steam generation with thermea.		
Performance factor of the HP-steam generation	2,8	
Annual electricity generation for steam generation	12.500	MWh/a
Electricity price	80	€/MWh
Annual steam costs	1.000.000	€/MWh
Annual cost savings *	715.000	€
Investment costs	1.250.000	€

**additionally: economies in investment, operating and personnel costs with regards to the process of re-cooling.*

We would like to offer you a profitability evaluation regarding your specific figures and conditions.

As generally known, heat pumps do not differ in terms of mechanical components from refrigerator machines. Both increase the temperature of thermal energy from a lower temperature level to a higher one. The difference becomes clear if the operation method is examined:

> Refrigerator machines use the “cold“ part with temperature levels below ambient air temperatures,
> Whereas heat pumps use the “warm“ part with temperature levels above ambient air temperature and suitable for heating processes.

To master this task, high-quality operating power, in most of the cases electrical energy, has to be employed. For evaluation purposes regarding the efficiency, the coefficient of performance ε is defined to express the cost-benefit ratio.

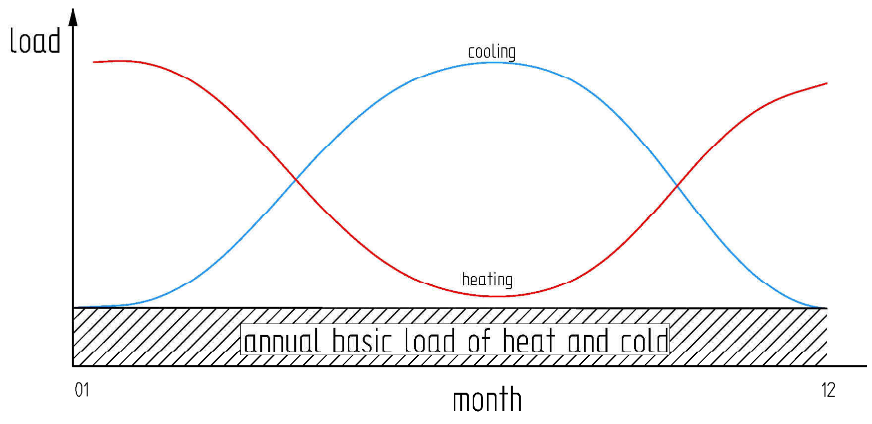
For the refrigerator machine applies: $COP_{RM} = \frac{\dot{Q}_0}{P_{el}}$ with: $\dot{Q}_0$ = refrigerating capacity
P_{el} = drive capacity

For the heat pump applies: $COP_{HP} = \frac{\dot{Q}_H}{P_{el}}$ with: $\dot{Q}_H$ = heating capacity.

When the application of a refrigerator machine is necessary, opportunities for using the “warm” part within the process, or for heating purposes in the surroundings, should always be identified. Consequently, also, when employing a heat pump the options for use of the “cold” part have to be questioned. If the “cold” and “warm” parts are used simultaneously, or “coupled”, so to speak, this is referred to as thermal coupling (TC).
The benefit is enhanced to $Q_H + Q_0$ with the coefficient of performance of the thermal coupling reflected in:

$$COP_{TC} = COP_{HP} + COP_{RM}$$

The highest possible efficiency is achieved if both heat quantities are required simultaneously, and all year-round. This would apply, for example, in hospitals or commercial building complexes, which have a year-round demand in cold water for process cooling, or climate control, and a high demand for fresh water at the same time.
Ill. 1 shows a common qualitative yearly average of heating, or respectively, cooling load. In winter, low outdoor temperatures cause an increase in heat load with only a basic cooling load, e.g. for cooling of machines or data processing instruments. By contrast, in summer an increased cooling load and only a basic heat load for process heating (e.g.: hot water generation) is needed due to the warm climate. In an ideal situation the shared annual basic load is covered by a highly efficient TC, achieving substantial cost-savings.



Ill. 1: Qualitative heating load development with shared basic load over one year period

Thermal Coupling

Hot drinking water supply involves a heating-up process (opposed to the process of keeping warm), which means that the thermal heat is used for a large temperature increase, and not in compensation of heat loss or for vaporizing processes.
Thermea. CO_2-large scale high temperature heat pumps are most suitable for such heating-up processes as they achieve noticeably better process-related performance results than conventional machines.

Comparison with a R134a-Heat Pump*

> Cold water temperature: 6 °C
> Return temperature of cold water: 12 °C
> Temperature of cold drinking water: 15 °C
> Temperature hot water: 65 °C
> Coefficient of performance R134a-HP: $COP_{TC} = 4{,}9$
> Coefficient of performance thermea.-HP: $COP_{TC} = 6{,}3$

Under the process temperatures mentioned above the thermea.-heat pump with screw-type compressor achieves the following performance factors:

> Refrigeration capacity 600 kW
> Heating capacity 800 kW
> Electrical operating power 220 kW

Profitability

The application of a thermea. heat pump with thermal coupling is, in general, economically advantageous. The following factors have a considerable impact on the repayment period:

> Investment cost of the entire system:
Therefore, especially peripheral, costs have to be considered with regards to the existing installation (how costly is integration into the cold water network, how costly is connection to the sink water, etc.).
Investment costs of the thermea. heat pump: 450-500 €/$kW_{\text{heating output}}$
(Within the same range as heat output mentioned above)
> Current prices for thermal-, cooling-, electrical energy
> Number of operating hours of TC-operation, as well as operating hours of the uncoupled heating or cooling processes (only applies for certain construction types)

Example

Capital expenditure	500.000	€
Price of thermal or cooling energy	35	€/MWh
Price of electrical energy	100	€/MWh
Operating hours TC	6000	h/a
Repayment period	3,1	a

**R134a-heat pumps represent the state of the art technology.*

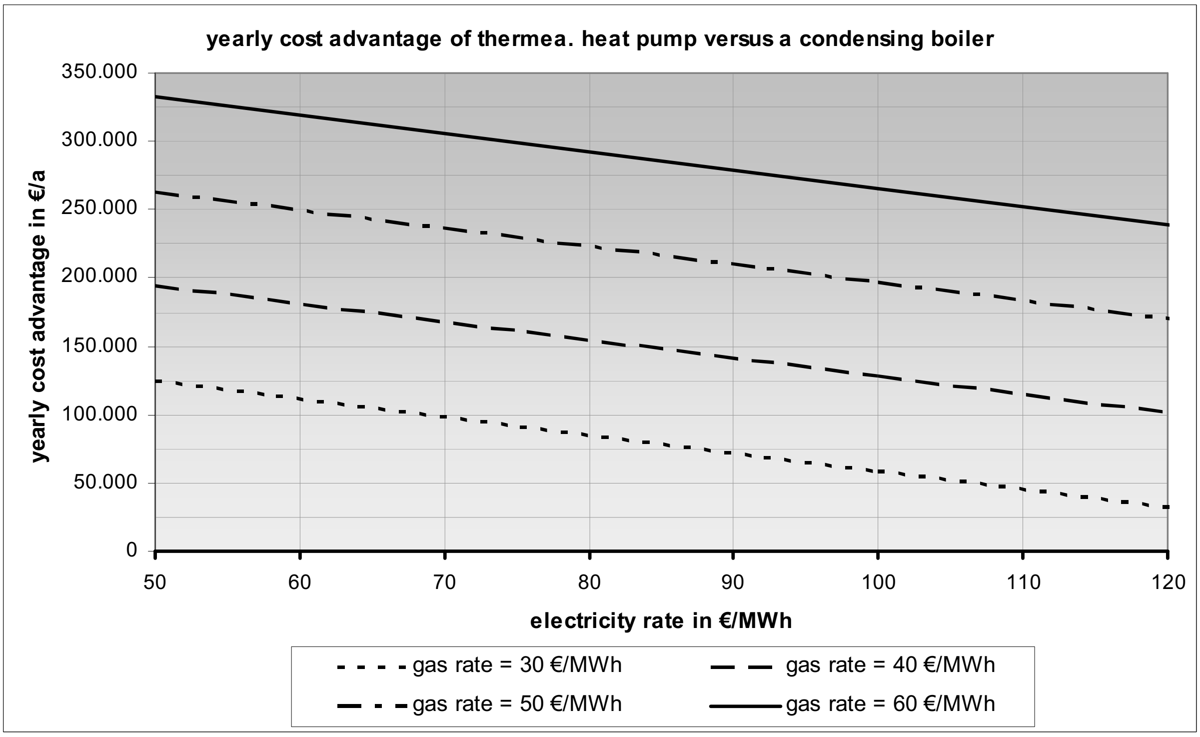
Worked Sample – thermea. Heat Pump vs. Condensing Boiler

If there is industrial waste heat (see information in “Industrial Waste Heat”) as well as an appropriate industrial heat demand on an industrial site (see information in “Industrial Heat Requirement”), the application of a large scale, high temperature heat pump is profitable.

For an evaluation of whether or not to make such an investment, and if it is cost-efficient to do so, along with the calculation of economic profitability, special site-related factors must be carefully considered.

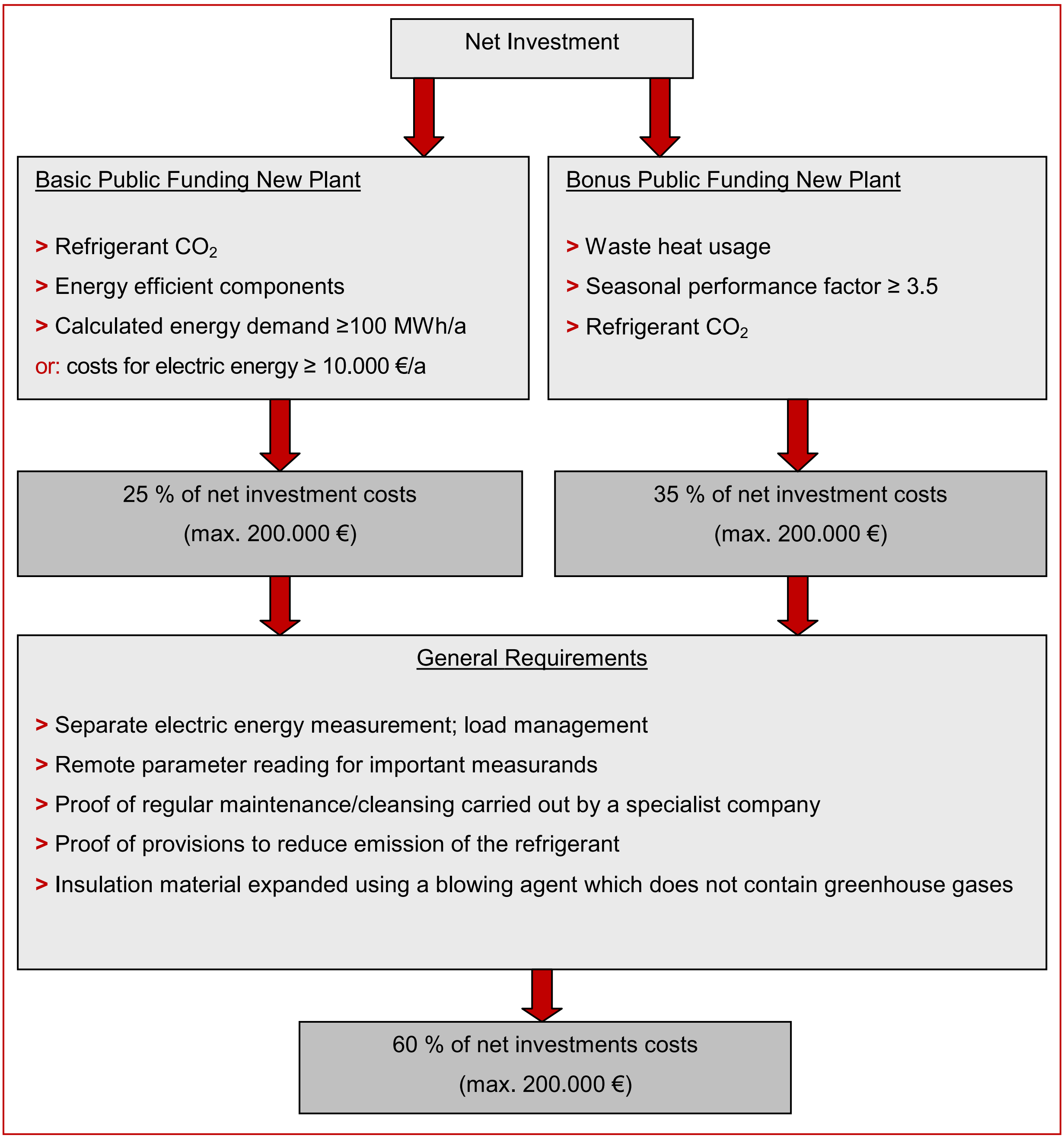
Decisive factors for the evaluation of profitability are always the operating costs (respective energy costs, service costs and personnel expenditure) and the investment costs. The operating costs strongly depend upon the annual running time. Additionally, it has to be taken into account that the energy costs within industry differ as the case arises. Bulk costumers attain special conditions, which leads to the advantage of lower rates.
The investment costs of a heat pump are higher in comparison to a condensing boiler. These additional costs must be refinanced by lower running costs. For this reason, a profitability calculation for each application is recommended.

The diagram shows the yearly cost advantage of the thermea. high temperature heat pump in comparison to a condensing boiler. The rate of electrical energy is shown on the axis of abscissa with the annual cost advantage on the ordinate. The heat pump in combination with a hot water vessel enables you to avoid higher demand charges for electrical power, as it is not necessary to run the heat pump during peak load times.
Gas is the parameter of the curve. An annual running time of 5,000 hours forms the basis of the diagram. With the help of this diagram, a first evaluation of a heat pump application is possible.



Thermea. Heat Pump with Working Fluid CO_2

The working fluid CO_2 is a natural substance which is increasingly used in technical processes in order to supersede the halogenated substance carbon hydride. From the 1st of September 2008 applications for basic and bonus public funding can be submitted at the German Federal Office for Economics and Export Control. According to publications of the Federal Ministry of Environment, Nature, Conversation and Nuclear Safety you can not only receive the basic public funding of 25 % but also the bonus public funding in the tune of 35 %, if you opt for a heat pump system with CO_2 for waste heat recovery. The essential requirements for the approval of government aids are illustrated in Ill. 1. These qualifications are fulfilled and even exceeded by thermea. heat pumps.



Ill.1: Overview: Directive on Public Funded Schemes for Industrial Refrigeration Plants provided by the Federal Ministry of Environment, Nature, Conversation and Nuclear Safety; (Illustration: thermea. Plc.)

Heat Contracting

A Modern Way of Saving Energy.

For most companies, heat supply is a necessary and fundamental task. This assignment ties up capital, requires personnel expense and is mostly beyond any competencies found internally within the company. For assembling a heat pump, companies incur greater expense, for a start. The investment costs, (hardware) which are higher compared to a boiler, have to be re-financed through economies within the operating costs. Considering the current price level this can be achieved, depending on the individual case, after three years operating time.

Heat contracting offers an intelligent and easy alternative to master this „barrier“ of high investment costs. A heat supplier (contractor) installs a heat generator on your premises in order to operate it and subsequently supply you with the required heat through the interface of your heating system or production plant. With a measurement device, the delivered heat is recorded.

The price of heat consists of three essential components:

- > annual base rate
- > servicing and meter charges
- > energy prices.

Thus, the calculated heat price is agreed by a contract offering cost certainty for the entire run-time of the contract.
thermea. together with its qualified partners, offers you the opportunity of heat contracting

Our Services are:

- > Consulting, planning, financing, delivery and assembling of the new system,
- > Heat metering and heat cost billing,
- > Operating security through the use of „twenty-four/seven” supervision and remote diagnosis,
- > Twenty-four/seven emergency service, and trouble shooting 24 hours per day,
- > Full warranty service including working hours for all of our plant components.

Your Benefits are:

- > You save energy costs,
- > You are provided with cutting-edge technology,
- > You do not need reserve assets for servicing and maintenance,
- > You have a price guarantee,
- > You have no operating risk,
- > You are at high operating security,
- > You do not have to concern yourself with technologies you are alien to,
- > You have no administration costs,
- > You generate environmental friendly heat through up-to-date technology,
- > **You only pay for the actual heat used and economically generated.**

Competencies

The **thermea. Energiesysteme** Plc. is a company within the **bw-energiesysteme group**, founded by Dr. Bodo Wolf and Dr. Beate Mikoleit.
Since 1960, Dr. Wolf has been committed to the field of coal and energy management. Acting, among others, as director of research at the German Institute for Heat and Fuel Technology, he has worked as an independent entrepreneur since 1990.
As managing partner, he established the holding company CHOREN Industries, subsequently leading it to economic success.
As holder of numerous industrially-used patents, he has received various recognized awards.
Today, Dr.Wolf is the chairman of the management board of the bw-energiesysteme group.
Dr. Mikoleit is the manager of bw-energiesysteme. For over 18 years, she was responsible for the management of the architecture firm 'Mikoleit', within the field of engineering and interior architecture. It is her objective to combine energy-conscious thoughts and actions with architecture.

thermea. Energiesysteme Plc. was found in March 2008. Entrepreneurs, engineers and technicians of thermea. have over 30 years experience in the field of cool and heat pump technology. The team is also blessed with many young members of staff. Our knowledge, combined with our experience within the field of plant engineering and energy management, as well as the commitment of young members of staff, reflects our competencies.

Dipl. -Ing. (FH) Steffen Oberländer,
is a co-partner and director of thermea. Energiesysteme Plc.. His wealth of experience in the area of machine and plant engineering, as well as in technical building equipment, is of great importance for the company. For more than 15 years, he successfully built and ran his own industrial business.

Dipl. –Ing. (FH) Ronny Schneider,
founded the thermea. Energie + Service Plc., together with Mr Oberländer, running it successfully for over 15 years. Today, Mr Schneider acts as an associate, as well as director of the Energiesysteme Plc.. Being a specialist in the field of technical building equipment, he can rely on many years of experience.

Prof. Eberhard Wobst,
is technical director of thermea. During his long time of service at the German Institute for Air Conditioning and Refrigeration (ILK) Dresden, he was in charge of research fields, especially involving numerous projects concerning refrigeration engineering. Before starting to work for thermea., he was actively involved in the sector on a voluntary basis, and still continues his teaching activities today.

Dr. -Ing. Walter Nestler,
works as engineering consultant at thermea. He is an acknowledged expert within the field of cool and heat pump technology, as well as fluid engineering. He has acquired a wealth of experience during his work at the Technical University of Dresden, and within the Industry itself. His publishings are of great interest for engineers in the field of cool and heat pump technology.

Objectives

Sustainable measures to protect the environment require a significant increase in the appliance of regenerative energies in order generate electricity within the next decades. The major challenge is that regenerative energies (sun, wind) are not permanently available, and thus can not correspond to the predominant demand.

The target of the thermea. Energiesysteme Plc. is it to develop decentralised energy storage methods in order to compensate for diurnal variation of the demand in electrical energy.

Therefore, the thermo-compression procedure (TCP) patented by Dr. Wolf will be technically implemented. TCP involves the storage of thermal energy generated by a CO_2-large scale high temperature heat pump. If required, heat can be used directly or be exuded during the work cycle.

By virtue of the complexity of the objective, the process is split into different steps:

> Development of the large scale high temperature heat pump, using CO_2 as a refrigerant
> Development of a thermal engine for the generation of electrical energy
> Combination of the above steps through the use of a storage-type plant.

The first part refers the development and construction of the CO_2 – large scale high temperature heat pump, which can be provided for application within the industrial sector. Already this sub-goal can make a substantial contribution towards the saving of energy resources and costs.

We would be glad to provide an energetic and economic evaluation concerning applications with the best prospects as well as any consultancy services that you may require. Furthermore, technical solutions for the use of waste heat or heat generation transcending the application of a heat pump will be considered if requested, for example, enabling a new technical solution, such as the generation of water vapour through the use of the heat pump.

Thermea. Energiesysteme Plc. and its partners provide heat preferably as a contractor, remaining the owner of the heat pump (see section “Heat Contracting”).

When employing a large scale high temperature heat pump, we can guarantee the following benefits to you:

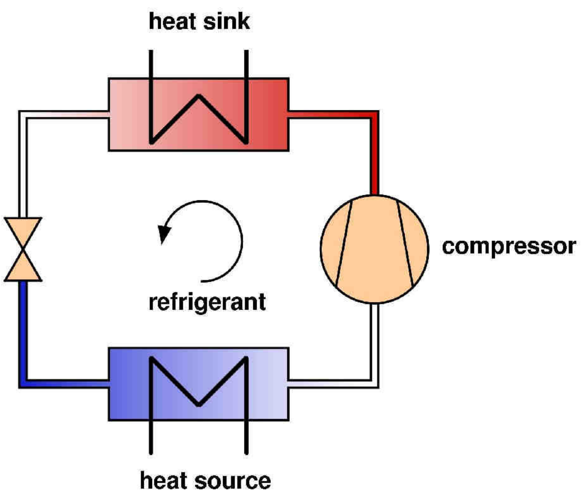
> Lower costs.
> No concerns about the technical equipment.
> You will become increasingly independent from the conventional energy market.
> And you can increase your environmentally-friendly image.

What is a Heat Pump?

Heat pumps are machines able to absorb thermal energy at a low temperature level (heat source), in order to increase this energy to a higher temperature level (heat sink) and subsequently supply it for utilisation (heating, hot water or process heat). During the process, mainly electrical power is used for the compression of the working fluid (and auxiliary units).

The working fluid runs through four different state changes within the machine:

> evaporation
> compression
> liquefaction
> expansion.



As soon as the compressor is running, low pressure is produced in the evaporator, so that the working fluid evaporates. The required heat of vaporisation is then withdrawn from the heat source.
This steam of the working fluid is compressed by the compressor, which results in a pressure rise. This increase of pressure caused by mechanical work substantially increases the steam temperature until it finally reaches discharge temperature.
The overheated steam is then cooled down and condensed in the condenser. The condensation heat which is released passes into the heating-circuit water, heating it up. After being expanded the working fluid is now again available in a vapour / liquid state to evaporate in the evaporator again.
Thus, the cycle of subcritical medium is closed.
In the information sheet „Special Features of the Heat Pump with Carbon Dioxide" the differences to the supercritical process of using CO_2 as working fluid are explained.

The energy efficiency of a heat pump is described by the (annual) operating factor (a); the quotient from the annually generated heat and the corresponding required operating energy being between 3 and 5, depending on the individual case. To organize the application of a heat pump as beneficially as possible, and thus achieve a high annual operating factor (a), the temperature of the heat source should be high as possible and the temperature of the heat sink should be at the lowest level. As the power consumption depends upon the temperature difference between heat source and heat sink, it should only be as large as actually required.

The outstanding advantage of the heat pump is that the generation of 100% heat energy requires only 25% power input. The remaining 75% is taken from the environment. This means that increasing energy prices will no longer have such a significant impact on the heat price. Therefore, the heat pump is clearly the power source of the future. Instead of burning sources of energy for the generation of thermal energy, they should be used under high efficiency levels to generate electricity for running heat pumps. Additionally, further use can be made of the waste heat arising from power generation.

But there is another remarkable ecological benefit. The carbon dioxide emission is reduced to 0.14 kg CO_2/kWh, and can even reach 0 kg CO_2/kWh if electricity from wind or sun energy is employed.
It is useful for comparison to note: oil-based heat generation: 0.31 kg CO_2/kWh and Gas: 0.24 kg CO_2/kWh respectively.

Heat Pumps are More Up-to-Date Than Ever!

The application of heat pumps has experienced an enormous upswing.
Presently, the focus is on the heating of one-family dwellings and semi-detached houses.

Heat source	Number	Growth
Soil/brine	12.373	+59 %
Soil direct evaporation	545	+34 %
Water	1.725	+48 %
Air	10.515	+163 %
Others	354	+38 %
Reversible heat pump	318	-9 %
Warm water heat pump	4.194	+54 %

Development of low performance heat pump sales at mid-year 2007 in comparison with the previous year in Germany (source:IZW)

The application of heat pumps with high performance levels within the industrial sector offers particular economic profitability. Energy savings to be achieved are considerably higher, as with small heat pumps for the heating of buildings. The potential is estimated to be about 11 % of the industrial effective energy demand. It is essential to make this remarkable capability accessible.

The Heat Pump is the Future!

The acceptability of the heat pump depends on the economic-efficiency, i.e. the higher investment costs (hardware) in comparison with the boiler have to be refinanced by economies within the operating expenses. At the current price level, this can be achieved within 4 years depending upon the individual case (see information in „Profitability of Heat Pumps"). The future tends towards heavy increases of energy prices which will, together with the numerous benefits of heat pumps mentioned above, reinforce the interest in the field of heat pump technology all the more.

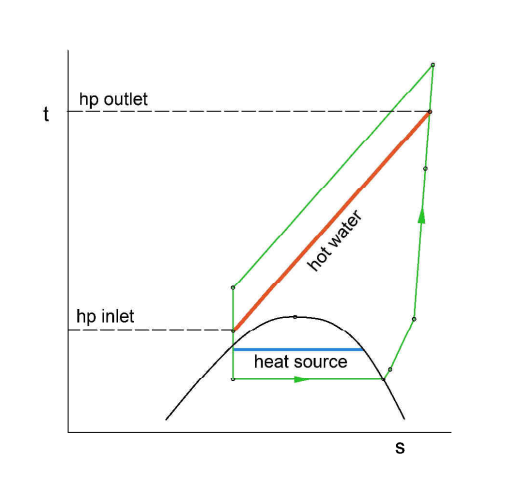
The application of heat pumps will become more and more remunerative in the near future as:

> cost savings will continue to increase,
> the impact of rising energy prices will diminish,
> Corporate image benefits will be reinforced, especially with regards to environmentally friendly heating systems.

Special Features of Heat Pumps with Carbon Dioxide

Preface

The heat pump with carbon dioxide (CO_2) as a refrigerating agent (working fluid) differs from the conventional heat pump as it offers a “floating” temperature change of CO_2 on the part of the heat consumer appliances. Whereas the working substance is liquefied at a constant temperature during the subcritical process, the heat emission does not take place with constant temperatures within the supercritical range. Temperatures of the heat transfer medium (hot water) increase when heat is transmitted. The changes in temperatures can be balanced out so that the temperature differences between CO_2 and the heat transfer medium are minimised. The better this can be achieved, the more advanced the efficiency of the heat pump processes will be, producing high hot water temperatures at a favourable energy efficiency ratio. Conventional heat pumps with constant condensing temperatures can only achieve a similar efficiency if the temperature of the heat transfer medium is low.



Temperatures of the CO_2-heat pump

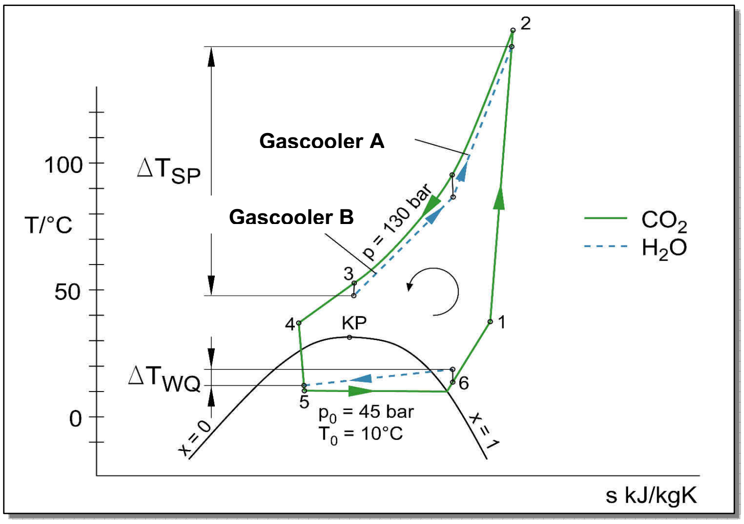
When choosing the working substance CO_2, the current developments in the field of refrigerants are also considered. CO_2 is taken from the natural metabolic cycle. Thus, it neither additionally contributes to the greenhouse effect nor to the destruction of the ozone.

Compared to other refrigerating agents, carbon dioxide is not affected by restrictions or even bans.

Ill. 1: Temperatures of the heat pump process in the temperature-entropy-diagram

Thermodynamic process description

The heat pump cycle is shown in the temperature-entropy-diagram (T-s diagram) Ill.2. The special feature: high-pressure side within the supercritical area, is pointed out.
In the T-s diagram temperatures are charted in on the ordinate and the specific entropy on the axis of abscissa. The convex curve with x=0 and x=1 separates the vapour phase of the CO_2 above the curve from the diphase region below the curve. At x=0 the CO_2 is liquid, at x=1 it is present as dry saturated steam. Within the so-called critical point (CP) the curves x=0 and x=1 coincide. This area should be avoided during technical processes.
At point 1 there is overheated CO_2 –vapour which is compressed by a compressor to point 2 through the supply of technical work. In this example the pressure increases from 45 bar up to 130 bars. Temperature rises from 50 °C to 150 °C. At point 3 this highly compressed and hot gas is cooled down to 52 °C in at least two gas coolers, here ca lled A and B, at about the same pressure. In the counter flow, water acting as a cooling agent is heated by the CO_2- gas (dotted curve). The water is heated up about ΔTsp (in this example from 47 °C up to 145 °C) and afterwards stored or directly conducted to be used.



Ill. 2: Heat pump process within the temperature-entropy-diagram

Between point 3 and 4 a so-called internal heat exchange is installed. The heat which is released at the CO_2 high pressure side is then returned back to the low pressure side of the process at the points 6 and 1. The purpose of this form of heat transfer is to shift point 1 rightwards and thus achieving higher compressor temperatures. At the points 4 to 5 the gas is expanded in an expansion machine until it reaches diphase level. At 5 to 6 the vaporisation of the liquid CO_2, as well as a slight overheating is carried out. The required heat is withdrawn from the heat source (environment) at the highest possible temperature level; e.g. from sewerage. As the process will pass through the diagram towards the left, it is also referred to as thermodynamic "counter clockwise process".

The energy efficiency of the heat pump at a certain point in time is expressed through the coefficient of Performance COP_{HP}. It is the quotient from the instantaneous heat output $\dot{Q}_H$ (benefit) and the respective driving power P_{KL} (effort):

$$COP_{HP} = \frac{\dot{Q}_H}{P_{KL}}$$

Theoretically, the highest obtainable performance factor COP_C can also be expressed by the means of temperatures:

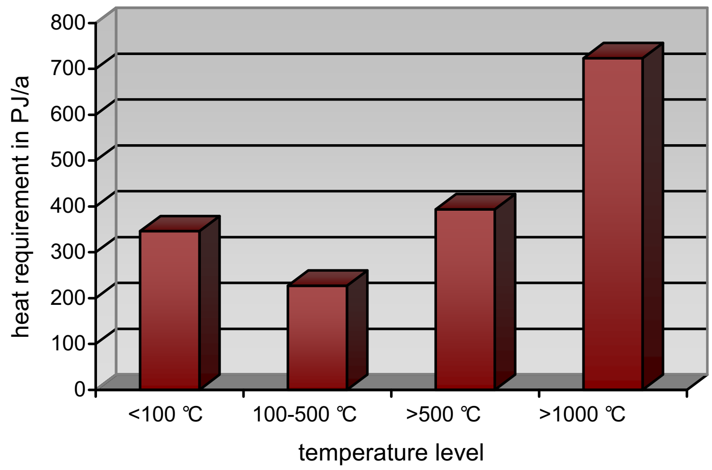
$$COP_C = \frac{T_m}{T_m - T_0}$$

T_m: thermodynamic mean temperature in K (close to the average hot water temperature)
T_0: evaporating temperature (close to the heat source temperature) in K
COP_c: Carnot performance factor stands for the high-pressure sided supercritical process

This equation demonstrates that the COP strongly depends on the average temperature of the hot water. Consequently, low input temperatures have to be achieved if high hot water output temperatures are required. (s.Ill.1.).

Industrial Heat Requirement

In general, the highest heat requirement for manufacturing companies, next to the buildings' heating systems and hot water treatment, is demanded by processes.
Approximately 65% of the secondary energy produced by German manufacturing companies is used to produce process heat. Thereby, one can distinguish between different temperature levels of thermal heat as shown in the diagram below.



Structure of the industrial heat demand in the Federal Republic of Germany, 2003 [Source: Stat. Federal Statistic Office]

The use of large scale high temperature heat pumps enables the generation of thermal heat up to 130 °C, thus making it possible to annually cover approximately 400 Petajoule (> 100.000.000 MWh) of Germany's industrial demand only by heat pumps. That corresponds to a quarter of the industrial overall heat requirement. Hence, employing heat pumps within the industrial heat generation process offers remarkable opportunities for energy conservation.
Predominantly, that means cost-saving for companies, but also constitutes a considerable benefit for the environment and its resources.

Industrial Heat Sinks

Heat sinks are heat consumer appliances which can be supplied by large scale high temperature heat pumps because they require temperature levels of up to 130 °C, as shown within the following examples.

> Processes of Drying

The use of heat pumps can dry products such as wood, wood chips, and sewage sludge, as well as feeding stuff and foodstuffs. During the process of drying, water vapour is absorbed from the goods to be dried by warm air. This air is cooled down on the cold surfaces of the heat pump's evaporator, dehumidified and subsequently reheated in the gas cooler before being fed to the goods again.
In general, the temperature of the circulating air differs between 40 °C and 80 °C. Alongside the remarkable energy conservation, the closed air cycle is a significant advantage of the so called condensation dryer. Thus an environmental load of contaminants and unpleasant odour can be widely avoided.

Industrial Heat Requirement

> Washing Processes

In many cases industrial washing processes require hot water, therefore fresh water is normally preheated to 40 ℃ in counter current to warm sewa ge water and later heated from this 40 ℃ until the required washing water temperature is achieved. When washing textiles, temperatures between 60 ℃ and 90 ℃ can occur depending on th e washing programme.

During the dyeing process of textiles, fresh water is often heated until up to 80 °C inside of the machine due to technological reasons.

Additionally, in cosmetics production hot water with 85 °C is commonly used for the cleansing of production facilities.

> Heating of Process Water

Warm or hot water is, for example, required in the process of starch production. Here, water with temperatures of about 80 °C is used for releasing starch in order to steam strip it afterwards into different levels.

During these chemical productions processes, large scale high temperature heat pumps enable the preheating.

> Heating of Process Air

Warm or hot air is used as a means of conveyance during production processes. Hence, the gluing of chips during the flake board production can be carried out during their transport. For that purpose ambient air is heated from outdoor temperatures up to 110 ℃.

> Heating of Buildings

The demand in heating of buildings is often influenced by very high rates in air renewal. A high rate of air ventilation is required to prevent, for example, that the concentration of harmful substances or odours in the work area is exceeded. As the re-circulation of air is not sensible in this case, waste heat recovery from discharged air through the use of heat exchange devices is a beneficial alternative. As the additional heat output still remains considerably high, it could be covered by heat pumps. Furthermore, the number of operating hours is significant compared to static heating systems, due to the high proportion of external air. Additionally, this can be increased if there is greater demand in warm water (e.g. shower rooms for members of staff). Therefore, the application of heat pumps regarding the heating of building sites should be positively considered within manufacturing companies.

> Steaming Processes

Steam is employed in almost all manufacturing companies, whether as a heating medium or for cleansing purposes. A special case of cleansing is the steam regeneration of activated carbon filters in order to recover solvents. During this process activated carbon loaded with solvents is vaporized. Subsequently, the desorbat (steam-solvent mixture) is condensed and extracted in different phases. As the demand in live steam is high, respectively substantial amounts of water are to be heated in order generate steam. As the condensation of the desorbat provides an adequate amount of industrial waste heat, the preheating of feed water through the use of a large scale high temperature heat pump is by all means recommendable.

In many industrial processes expensive heat energy is either required (see information on "Industrial Heat Requirement") or generated by converting mechanical energy. In any case, this heat must be eventually conducted from a product or process into the environment, through the use of cooling facilities, as a waste- product.

Energy requirements often constitute the largest proportion of a company's operating costs, for which reason it is sensible, especially because of economic and energy-efficient concerns, to use the waste heat which has been created. On the one hand, that means energy requirements for heat generation can thus be reduced, on the other hand, re-cooling systems can be discharged.

Released heat can also be considered as an emission. In general, certain temperature thresholds apply for sewage disposal of cooling water into surface water, or the sewerage system, which is increasing the cost of the course of treatment.

Opportunities for use from the technical perspective are considerably versatile. Ranging from simple waste heat recovery using heat exchangers up to direct usage of waste heat, for instance in district heat systems, there are already possibilities. Only rarely, waste with lower temperature levels which can no longer be used in terms of heating purposes, is re-used, even though it constitutes an ideal heat source for a heat pump that could re-gain another fraction of this expensively generated heat.
Such waste heat potential occurs in almost any industrial company. Waste heat is released in the form of warm water or warm sewage into the environment as shown in the following examples:

> Process Cooling Water

Discharging large amounts of heat into the environment is normally carried out by spraying cooling water inside a cooling tower, where the cooling water is partly evaporated within an air flow, cooling down the remaining cooling water. Another method is the direct usage of cooling water from surface water. In this process thresholds regarding temperature, as well as quantities, have to be taken into account in order to protect ecosystems.
The application of a heat pump makes it possible to cool down the cooling water directly through the evaporator of the heat pump, in order to conduct it to further processes and simultaneously reduces the fresh water requirement.

Ill.1: Cooling towers with vapour formation (product image Company Gohl)

> Sewage

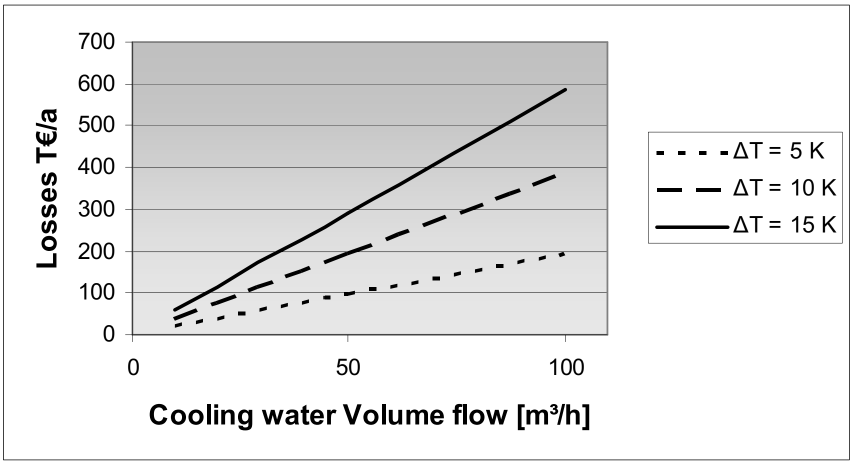
Contaminated sewage, mostly also containing a certain heat quantity, is the result of many washing and cleaning processes. As the discharge of these heat quantities into the drain system is either restricted or cost-intensive, the application of heat pumps in this area again offers a double-benefit: it reduces the sewage temperature and generates re-usable heat.

> Exhaust Air

In the air, heat occurs in two different forms. There are the so-called ‘sensible’ and ‘latent’ (“tactile” and “hidden”) thermal capacities. When cooling down air the first step is to withdraw sensible heat. After going below the dew point and during the condensation of humidity, latent heat is additionally released. Therefore, especially humid air, occurring for instance in drying processes, is a good heat source for employing a heat pump. Likewise, the condensation on the surface of the heat pump’s evaporator provides an even more intense heat transmission.

Heat is Your Money!

To clarify the loss caused by unused heat, the “given away” heat quantity can be offset against the costs of heat generation. The diagram shows the annual financial loss of expensive and unused heat energy caused by employing a cooling tower, although the technical and energetic effort of cooling systems is not taken into account. In the majority of cases, cooling towers are run with a variation of temperature between 5 and 10 K whereas cooling water volume flows above 100m³/h as well as a continuous operation are not unusual.



Assumption:

- Heat price 42 € (per megawatt hour*)
- Operation of cooling tower 8 h/d

**) Source: Public Services, Munich*

Possibilities for Heat Recovery

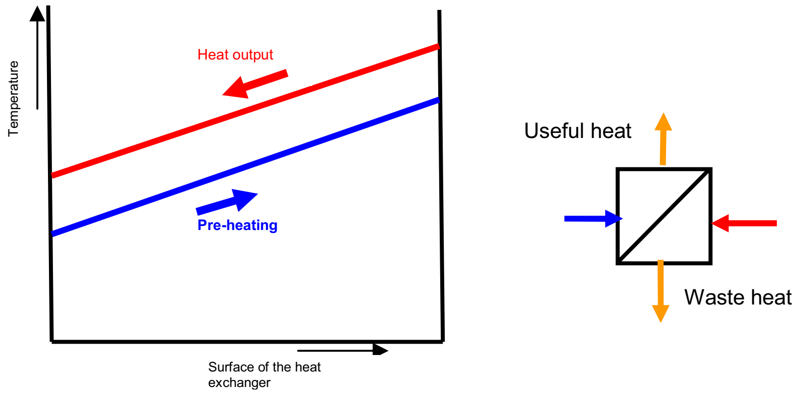
Making waste heat from technological processes reusable is the target of waste heat recovery. For achieving that there are several options:

> Heat pump

Using heat pumps is the most efficient form of waste heat recovery. In some cases, however, the expenses, which are higher than compared to other methods, are not justified. Further information regarding the advantages and disadvantages of waste heat recovery systems can be found under "Waste Heat Recovery Using Large Scale High Temperature Heat Pumps".

> Heat exchanger (recuperator)

If waste heat is developed at a temperature level which is above that of the air or fluid to be heated, pre-heating can be conducted through the use of heat exchangers (Ill. 1).
This is common practice in many production processes.



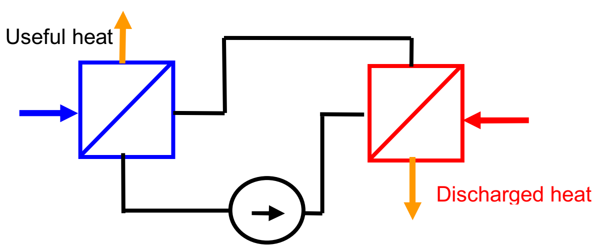
Ill. 1: Heat exchanger (recuperator)

This solution is generally very profitable. Besides the purchasing costs for the heat exchanger, the only additional investment requirement goes towards pumps and piping.
Disadvantages of this solution are:

- > Both material currents have to be locally consolidated.
- > With reference to theoretical marginal cases, the heating can be carried out until the input temperature of the waste heat flow is reached. (This restriction does not apply for heat pumps.)

> Recirculation systems

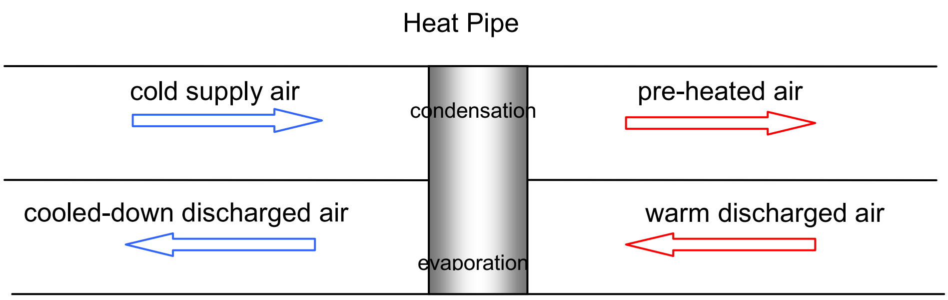
If the consolidation of the different material currents is too costly and complex (e.g. if it requires the installation of air ducts of a large diameter), a heat transport system as shown in Ill.2 can be installed. It uses a heat transport fluid (water in the simplest case), which is passed through the recirculation system.



Ill.2: Recirculation system, (KV-System)

> Heat Pipe

The heat pipe filled with the refrigerating agent is embedded within the system. The inside is at saturation state. If a warm medium is applied to one side, the refrigerating agent is vaporized there and subsequently condensed again on the other side. In doing so, the heat is conveyed very resourcefully. The return transport of the liquid refrigerating agent is either carried out through gravity or capillary forces. Several of these pipes are bunched together. There are also techniques to lay heat pipes in a laminar position.



Ill. 3: Application of a heat pipe in rotary heat-exchanger systems

> Regenerator

Heat-loaded discharged air and to be heated supply air are locally combined. At this point a regenerator (an air-permeable, slowly rotating thermal mass) is installed, carrying the heat of the discharged air to the supply air. Hence, warm and cold air flow through the regenerator in turns. Please note that there is a certain amount of leakage between both air flows. These appliances are also available for use in the field of heat and mass transport.

> Direct Use

Discharged heat of a cooling tower level can be directly used with low-temperature heating (e.g. floor and panel heating).

If this waste heat recovery technique is carried out in combination with the application of a heat pump, an elaborate economic evaluation is necessary. This results from the fact that recuperative solutions on one hand reduce the heat pump down to its "most efficient" operating condition, but on the other hand, the installation of a heat pump requires outlay costs for two hardware systems. Thus, it depends on the individual case, as to how beneficial it is to opt for such a system.

Waste Heat Recovery (WHR) is Sensible.

Dissipating unused heat into the environment means:

> economic losses,
> energetic losses and
> an environmental burden,

as every dissipated kilowatt hour has been generated under financial and energetic effort. On this account, waste heat recovery is always beneficial.

Capabilities of Conventional WHR-Systems are Limited.

The extensive amount of waste heat which is generated within the industrial sector (see information “Industrial Waste Heat Potential”) should be used through waste heat recovery systems. For this purpose certain requirements have to be considered:

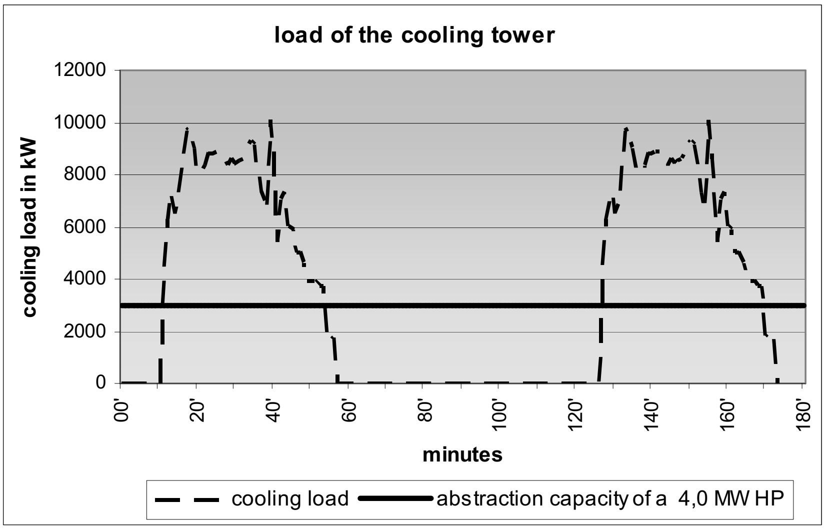
> convenient heat source at sufficiently high temperature
> existing heat demand at a given temperature level
> spatial proximity, required space
> high energy costs

All of these factors restrict the application of conventional WHR – systems (see “Possibilities for Waste Heat Recovery”). Because: If the heat source provides a temperature of 40℃ , heat with only 35 ℃ could be re-gained. If there are no users of heating circuit water with 35 ℃, the WHR just constitut es a pre-heating unit. If the waste heat is accumulating spatially far away, a WHR-system can turn out to be inefficient. In the end, energy prices have a decisive impact on the investment decision.

Large Scale High Temperature Heat Pumps Broaden the Opportunities for the Application of Waste Heat Recovery Systems.

> Almost all forms of heat sources, especially low temperature waste heat, are appropriate for the process of WHR. Without considering heat loss it is essential that the capacity of the heat source has to at least compete with the difference between heat demand and the operating power of the heat pump. (e.g. at a heat output of 1.000 kW and 16 operating hours per day, 12.000 kWh must be taken from the heat source if the heat pump aims to achieve a coefficient of performance of 4).

> Ideally, waste heat and heat requirements are coinciding temporally. If that is not the case, a temporal displacement can be compensated for by the means of storages. Diagram 1 shows a typical discontinuous waste heat accumulation, along with the continuous heat loss of the heat pump that requires conventional waste heat storage.



Ill. 1: typical discontinuous waste heat accumulation

> The WHR using a large scale high-efficiency heat pump makes it possible to supply heat consumers with different temperature levels, in some special cases up to approximately 130 °C. The information "Special features of Heat Pumps with Carbon Dioxide" demonstrates that the application of thermea. large scale high temperature heat pumps provides high coefficients of performance, even with within a high operating temperature range, making applications accessible which could not even be considered for the efficient usage of heat pumps before.

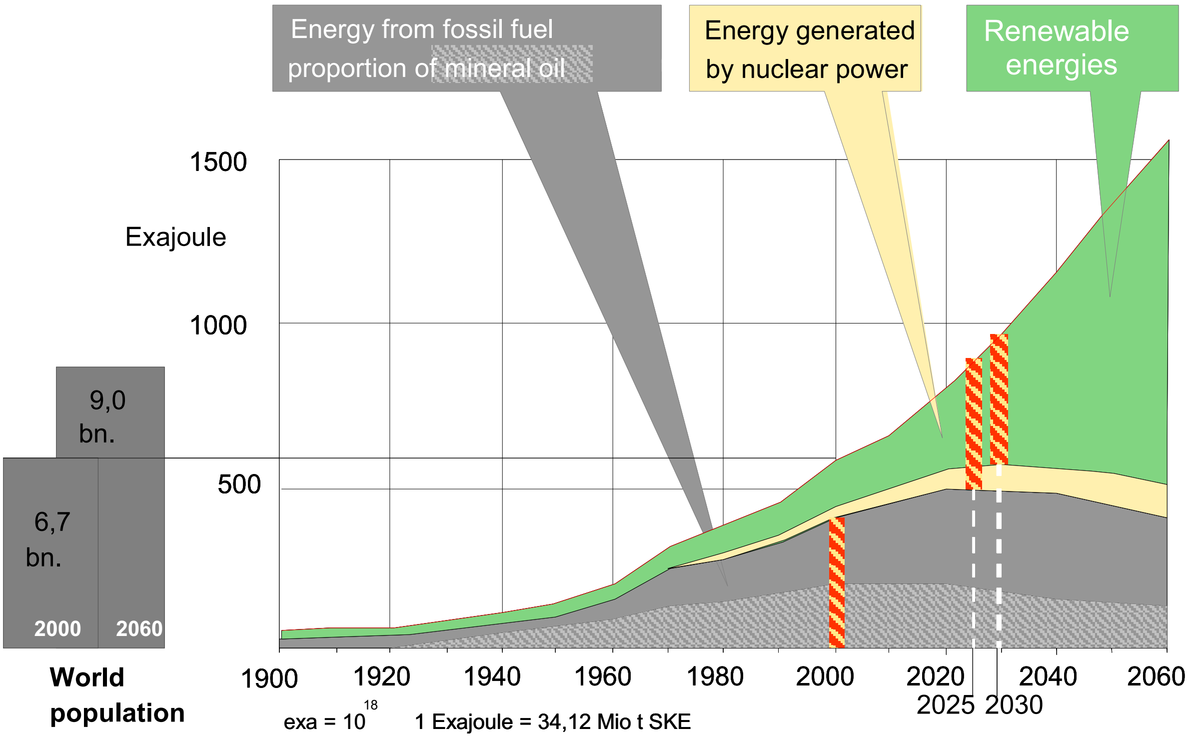
> The WHR-system with a large scale high temperature heat pump does not necessarily depend on the spatial proximity of the heat source and the heat sink, even though the investment is most favorable in this case of a close relationship between the two. Conceivably, one could say that the supply of surrounding consumers through a district heating network would be a beneficial option. Possibly, an industrial estate in the surrounding area could be interested to supply heat with cooling tower temperature levels. For the assembly of large scale high temperature heat pumps with high performances the EN standard 378 "Refrigerating systems and heat pumps. Safety and environmental requirements" has to be adhered. It does not constitute a particular barrier for using heat pumps. It is recommended (however it is not a requirement) to assemble the device in a machine room which is provided with the mandatory safety features and equipment. Alternatively, the heat pump can also be operated in a container or installed outdoors.

> If high energy costs lead to considering WHR, the application of a large scale high temperature heat pump is definitely justified. The necessary investment in the heat pump has to be re-financed by economies in terms of operating costs (see section "Profitability of Heat Pumps"). At the present level of energy prices, this can normally be achieved in just a couple of years. Future prospects in prices speak in favor of a further improvement in economic efficiency, as the heat pump uses mainly free of charge waste heat or environmental heat as well as just a very small proportion of electric energy to generate heat.

Large scale high temperature heat pumps allow waste heat recovery from low temperature waste heat and gain access to potential heat consumers due to a high operating temperature range and comparative spatial independence.

Trend Of Global Energy Demand

Technical advance is accompanied by an increasing requirement for energy. A study carried out by Shell AG in 2002 emphasizes that, in the future, this growth can only be covered through the use of generative energy sources.



Source: Shell AG, 2002

By 2050, 50% of the worldwide energy demand has to be provided by renewable energies – which is a result of the limited availability of the remaining non-renewable energy sources. This goes along with the growing environmental awareness which is expressed in the EU-Directive 20/20/20 of 23/01/2008 (20% renewable energy/ 20% improving efficiency/ 20% reducing green house gas emission by 2020). “Low-price energy from the socket” can no longer be considered as a matter of course, read the headline of the European Heat Pump Association (ehpa) in March 2008.

For running industrial processes the application of energy is indispensable. In most of the cases, energy costs account for a significant proportion of total expenditure. There are various examples of this, e.g. food stuff production, paper manufacture, flake board production, drying of products, hot water generation (see information in “Industrial Heat Requirement”). In total, 24.6% of Germany’s overall effective heat energy in 1998 was used for industrial purposes.

About 11% can be provided through the use of heat pumps.*) Especially new building constructions offer the opportunity to create ideal operating conditions for heat pumps, e.g. low temperature levels.
Existing equipment, on the other hand, can only give limited opportunities; such as replacing heat generators in accordance with the retention of existing thermal parameters.

**) IfE / TU Munich VDI-GET Annual Set of Figures 2000*

Trends of Energy Prices

It can be felt everywhere: through the daily news, at the petrol station or on the bill for heating oil, natural gas or electricity – **energy prices continue to rise**. There are many reasons for this. Opportunities to become more independent from these permanent price increases are, however, limited. Heat pumps can make a considerable contribution to this independence.

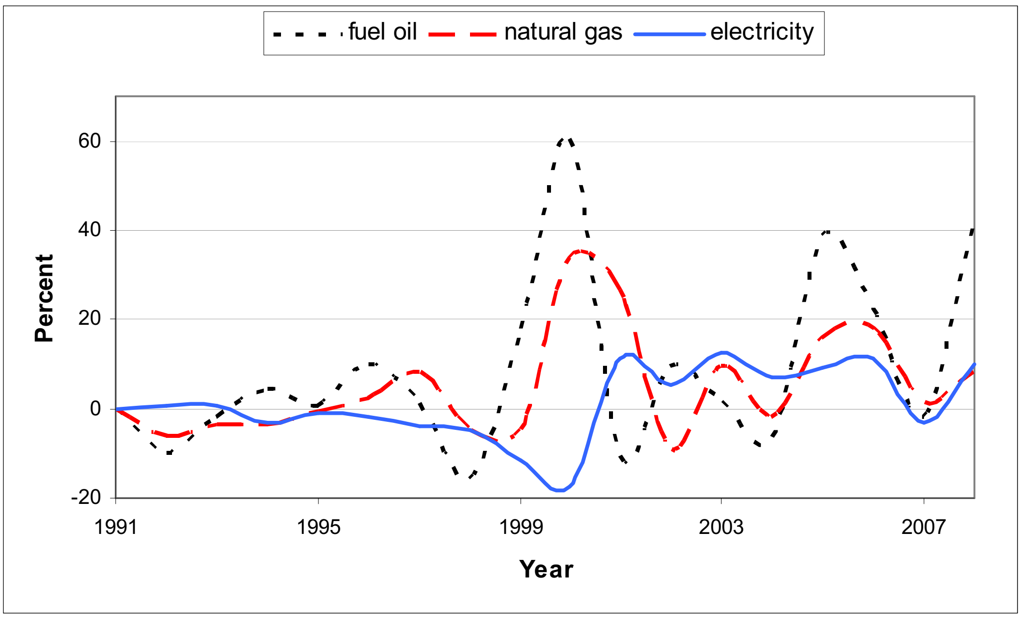
Factors of Influence
Energy prices depend on the following important factors:

> Price development on the international commodity market,
> Political stability of important producing areas,
> The current rate of foreign exchange (Euros to Dollars),
> Output policies of OPEC (Organization of the Petroleum Exporting Countries),
> Costs for generation and network transmission,
> Tax policies,
> Costs caused by emission trading,
> Profit margin of leading power suppliers.

In the future, import prices, driven by the constantly increasing energy demand of developing nations, will have a major impact on our domestic consumer prices
The developing competitive environments on electricity and natural oil markets have a calming effect on the development of energy prices. The consequences become clear if energy prices between 1998 until 2000 are considered – a time when electricity prices in Germany temporarily remained under the expected price level.

Price Development for Light Fuel Oil, Natural Gas and Electricity

Energy prices are subject to continuing price fluctuations. However, a well-defined price increase in terms of heating oil, natural gas and electricity is obvious. The ongoing examinations of prices for heating oil, natural gas and electricity from 1991 until July of 2008 are based on statistical data from the BMWi (German Federal Ministry of Economics and Technology).



Ill. 1: Development of Energy Prices for German industry (zero rated VAT)

With this data base, the progression shown in the table below could be determined:

Consumer Prices Industry (zero rated VAT):				
	Unit	fuel oil	natural gas	electricity
price in 1991	Euro/MWh	10,5	14,7	69,1
price in 07.2008	Euro/MWh	37,9	32,0	80,2
abs. Increase	Euro/MWh	27,4	17,3	11,1
Increase	%	262	118	16
Increase per year	%/a	7,9	4,7	0,9

The missing increase of electricity prices between 1998 and 2000 in comparison to prices for natural gas and heating oil is a result from the growing competitive environment. The difference between prices for heating oil and natural gas compared to electricity is expected to decrease in the following years. This development is interesting with regard to the application of electric-powered heat pumps.

By how much do energy prices affect the heat price if gas-fuelled boilers or heat pumps are employed?

Suggestions

> Degree of efficiency gas-fuelled boiler $\eta_{GK} = 1$

> Gas price 42 €/MWh, rate of increase 4.7 %/a

> Performance factor heat pump 4

> Electricity price 65 €/MWh, rate of increase 0.9 %/a

Energy costs

		Heat Pump	Boiler
Energy source		electricity	gas
Eenergy price	€/MWh	80	32
Performance factor/ degree of efficiency		4	1
Heat price 1. year	€/MWh	20	32
Price increase factor		1,009	1,047
Heat price 2. year	€/MWh	20,18	33,50
Additional expenditure	€/MWh	0,18	1,50

In comparison to gas, the application of a heat pump just requires 12 % additional expenditure annually.