Power and cooling from waste heat and solar

New possibilities for trigeneration

Waste heat from combined heat and power stations and industrial plants, as well as solar heat – these are the sources that, with the help of the Schukey technology, can be utilised to generate, as required, electricity as well as cooling for refrigeration and air conditioning. A new energy conversion technology combined with a rugged design improves energy efficiency and increases the possibilities for utilising solar energy. The first units are expected to be ready for the market in 2010.

Combined heat and power (CHP) contributes significantly to improving energy efficiency and, thus, reducing the environmental impact of While – due to attractive conditions of feeding electricity into the national grid – the electricity generated in CHP plants can be sold profitably and basically without any limitation, the waste heat produced in the process cannot be utilised adequately because of a lack of suitable local uses and distributional possibilities. This may still be acceptable with large plants owing to their relatively high electrical efficiency; however, the profitability of smaller plants and small-scale units with an electric output of less than 1 MW looks rather shaky if their waste heat is not sufficiently utilised.

The novel Schukey technology (ST) provides an opportunity to significantly increase the overall efficiency of CHP plants in that it uses the waste heat of the plant to generate additional electricity and produce cooling. The design of the system is simple: a Schukey engine converts (waste) heat into mechanical energy, thereby driving a generator as well as another Schukey engine used as a chiller. This directly cools the ambient air.

Thanks to its compact design, the ST can be installed in new CHP plants and retrofitted into existing ones. Moreover, it can also convert solar heat and industrial waste heat into electricity and/or cooling.

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One basic technology for power and cooling from (waste) heat

Universality as a principle

In an engine using the Schukey technology, two interlocking rotor-blade crosses, which can move against each other, rotate in one and the same housing. Via a shaft, each of the rotor-blade crosses is driven by a specially developed gear unit in such a way that the

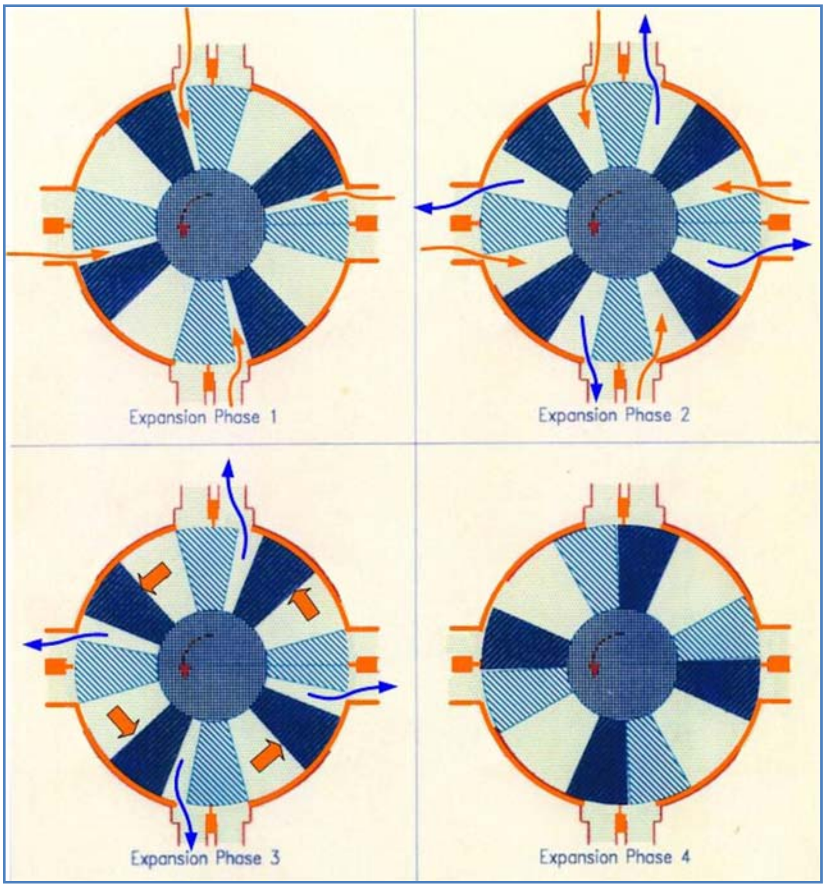


Fig. 1: Working as a combined heat and power engine in expansion mode (Clausius-Rankine process)

rotor-blade crosses do not turn uniformly at the same speed but out of phase with each other at alternately faster and slower speeds. As a result, the eight housing chambers formed by the rotor-blade crosses become bigger and smaller eight times per revolution, i.e. their cubic contents are compressed and expanded accordingly. (Fig. 1)

The arrangement of inlets and outlets matches the movements of the rotor-blade crosses in such a way that the latter also control the opening and closing of the inlet and outlet ports. There is no need for any closing mechanisms and controls, such as a camshaft and valves. The gearing design for the modulated rotation of the rotor-blade crosses is perfectly new, unique, and suitable for large-batch production. At any place during the rotation, it ensures a form-fit and low-loss power transmission.

From a mechanical engineering point of view, a Schukey engine is a displacement engine or, to be more precise, a rotating swing chamber engine. The ST can be used as an expansion engine with compressed air, hot air, hot gas, and steam; as a compression/expansion engine; as a component in an open or closed Brayton cycle, a Clausius-Rankine process, or an Organic-Rankine-Cycle process (ORC).

The efficiency rating of the ST is much higher than that of the energy conversion systems known so far (Otto, Diesel, Wankel, Stirling as CHP systems, and various compressors as cooling systems).

The basic unit is largely the same for all areas of application: it consists of less than 50 component parts, of which only 16 are moving. The movements of any moving parts are rotational without exception.

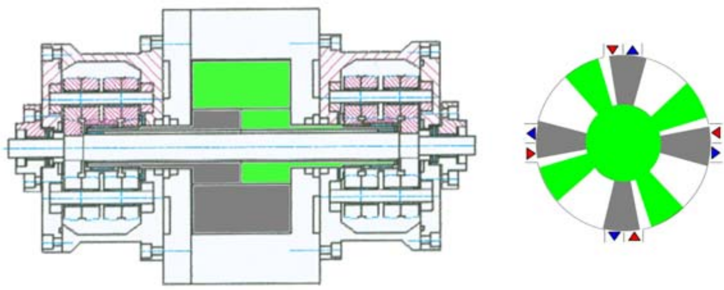


Fig. 2: Design of the Schukey engine, side and front view

P (kW)	T_e (°C)	Rotor (mm)	Drehzahl (U/min)	P_{max} (MPa)	V/U (Liter)
2,5	150	150	2600	0,11	2
6	120	150	1500	0,2	2
7,4	150	150	1500	0,2	2
19	120	220	1500	0,2	8
35	300	220	1500	0,2	8
40	400	220	1500	0,2	8
53	400	220	2000	0,2	8
100	400	300	2000	0,6	42

Table 1: Parameters and performance data for the ST as a heat-power engine

During operation, the Schukey technology shows the following advantages:

- compact design, therefore, perfectly suited for retrofitting existing CHP plants
- good part-load performance, particularly, if there is no contínous heat flow
- low rotational speed: there is no need for a geared transmission between the Schukey engine and the generator

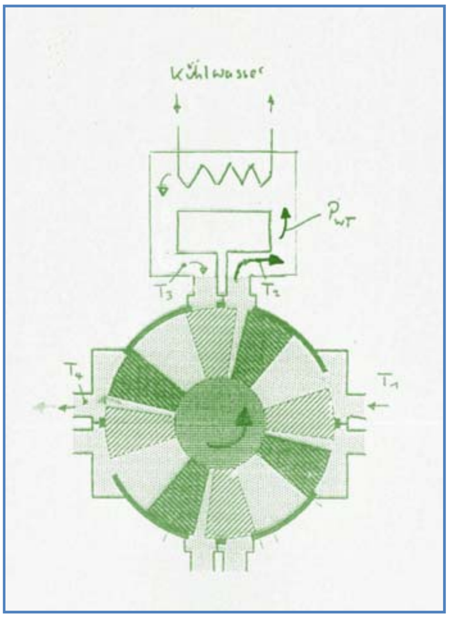
The maintenance and operating costs of a Schukey engine are very low. This technology is simple, rugged, and reliable.

Heat-power engine

The Schukey heat-power engine employs the principle of the hot-steam engine. Using the Clausius-Rankine process, the unit works as a pure expansion engine. The rotor-blade crosses, gear units, and control system interact in such a way that a high mechanical performance can already be achieved with a low inlet pressure.

During pure expansion operation, the eight (expansion) chambers formed by the rotor-blade crosses are enlarged four times per rotation by the medium under pressure entering the engine. (Fig. 2)

The demands on a technology that, in the low temperature and pressure range, can convert heat into mechanical energy are high. The technology has to



- have a very high flow rate to be able to offset the lack of specific energy of a medium,
- be small and compact, so that it can be used also in areas of limited space,
- feature extremely low internal frictional resistance, and

it has to be inexpensive and rugged for the engine to run profitably also with a – for physical reasons – lower efficiency.

Apart from the Schukey technology, no other technology known to date meets all these requirements.

Table 1 shows the power range covered by an engine using the Schukey technology to generate electricity from (waste) heat, and the respective operating conditions.

Fig. 3: Original drawing; working as a chiller in the compression-expansion mode (Brayton cycle)

Chiller

As a chiller, the Schukey engine uses the Brayton cycle without phase transition. In this way, the ambient air can be cooled directly.

The Brayton cycle requires a compression and an expansion engine. The Schukey engine is the only engine that combines a compression and expansion unit in one housing. Using the Brayton cycle, it achieves an efficiency comparable to that of conventional cold vapour processes.

An original drawing by the developer provides a good overview of how the chiller works. (Fig. 3)

(1) Ambient air flowing in (T_1) is compressed and, thus, heated (T_2).
(2) The heated air (T_2) is isobarically cooled using a heat exchanger (T_3).
(3) The cooled air under pressure (T_3) expands to ambient pressure, is thereby cooled to ambient temperature (T_4) and escapes.
(4) In a closed system (cold room, refrigeration room, office, etc.) the now cooled air is again fed into the process ($T_4 = T_{1new}$) and cooled down further.

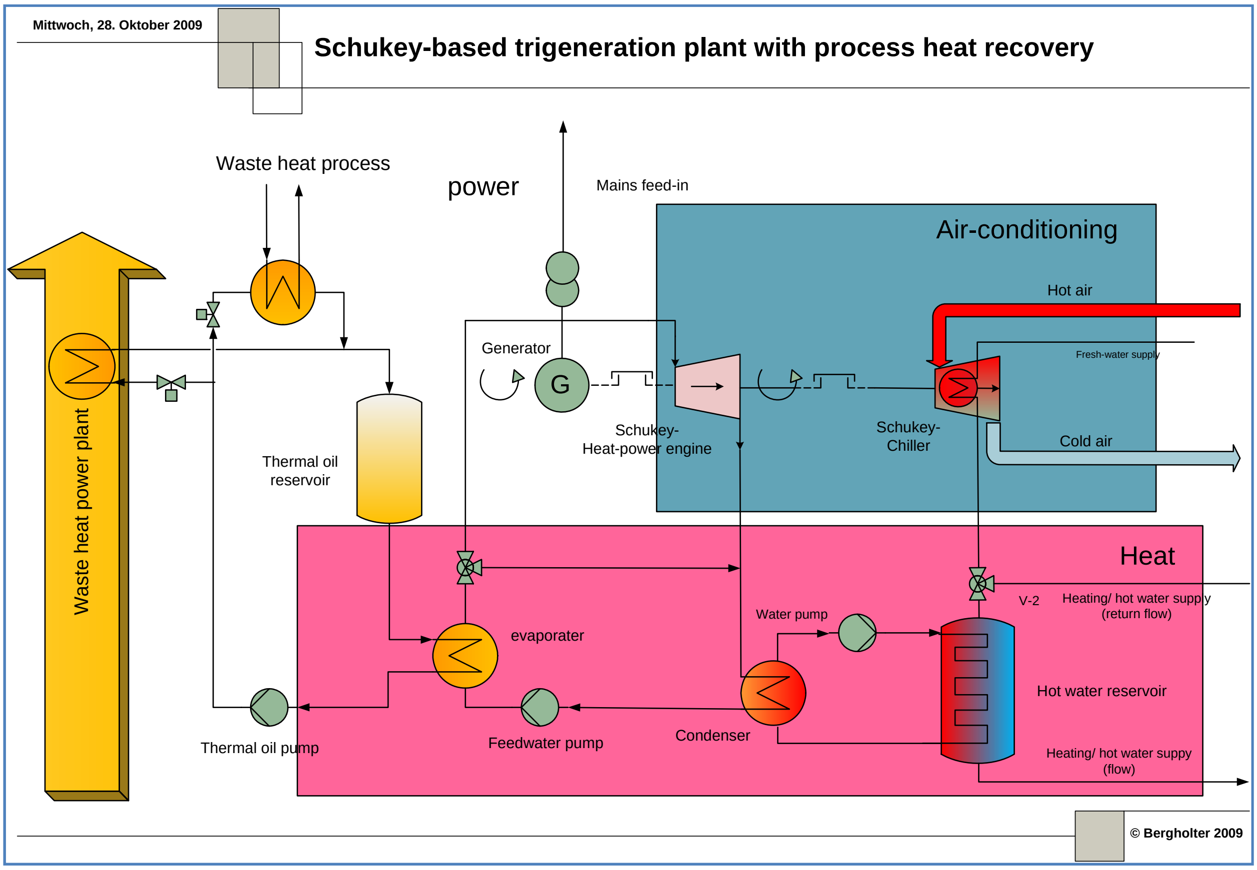


Fig. 4: Schukey synthesis-gas trigeneration plant with process heat recovery

The large displacement volume combined with relatively low compression (compression ratio of 1:1.3 to 1:1.8) renders the Schukey engine ideal for the Brayton cycle. The flow rate is controlled by the rotational speed. Mechanically adjustable control edges at the inlet and outlet of the compression-expansion chambers control the cooling capacity. The heat extracted with a heat exchanger can be used for heating purposes or service water.

The optimum position of each control edge makes for an optimised efficiency in the part-load operational range, so that the engine runs profitably within a wide rotational-speed and temperature range.
The efficiency of compression and expansion exceeds 90%, the coefficient of performance is between 3.2 and 3.9.

Trigeneration with the Schukey technology

Principle and technology

With a view to improving the efficiency of CHP plants while avoiding the use of electricity-dependent refrigeration technology, research in trigeneration can yield promising results.
The Schukey heat-power engine can convert waste heat of a comparatively low temperature into mechanical energy. Many CHP plants are able to provide this temperature level. Thus – as an alternative to an absorption chiller – an ST chiller, mechanically driven by the Schukey heat-power machine, can also be used to generate cooling.
The Schukey technology has a lot to commend it, for instance, the high coefficient of performance, which clearly exceeds that of an absorption chiller, as well as weight, volume, and capital investment, where the advantages of the Schukey technology are even more obvious.
Therefore, virtually every combined-heat-and-power plant that – permantently or temporarily – produces excess heat can be equipped, and in most cases also retrofitted, with the ST.

Pilot project "synthesis-gas CHP plant"

The allothermal steam reforming process turns a raw material (currently wood chips, later residues from the edible oil production) into high-purity hydrogen, which is then converted into electricity using a gas Otto engine.
With the help of the Schukey technology, the waste heat of this plant is converted into additional electricity and cooling.
In addition to the waste heat from the flue gas, this plant type also

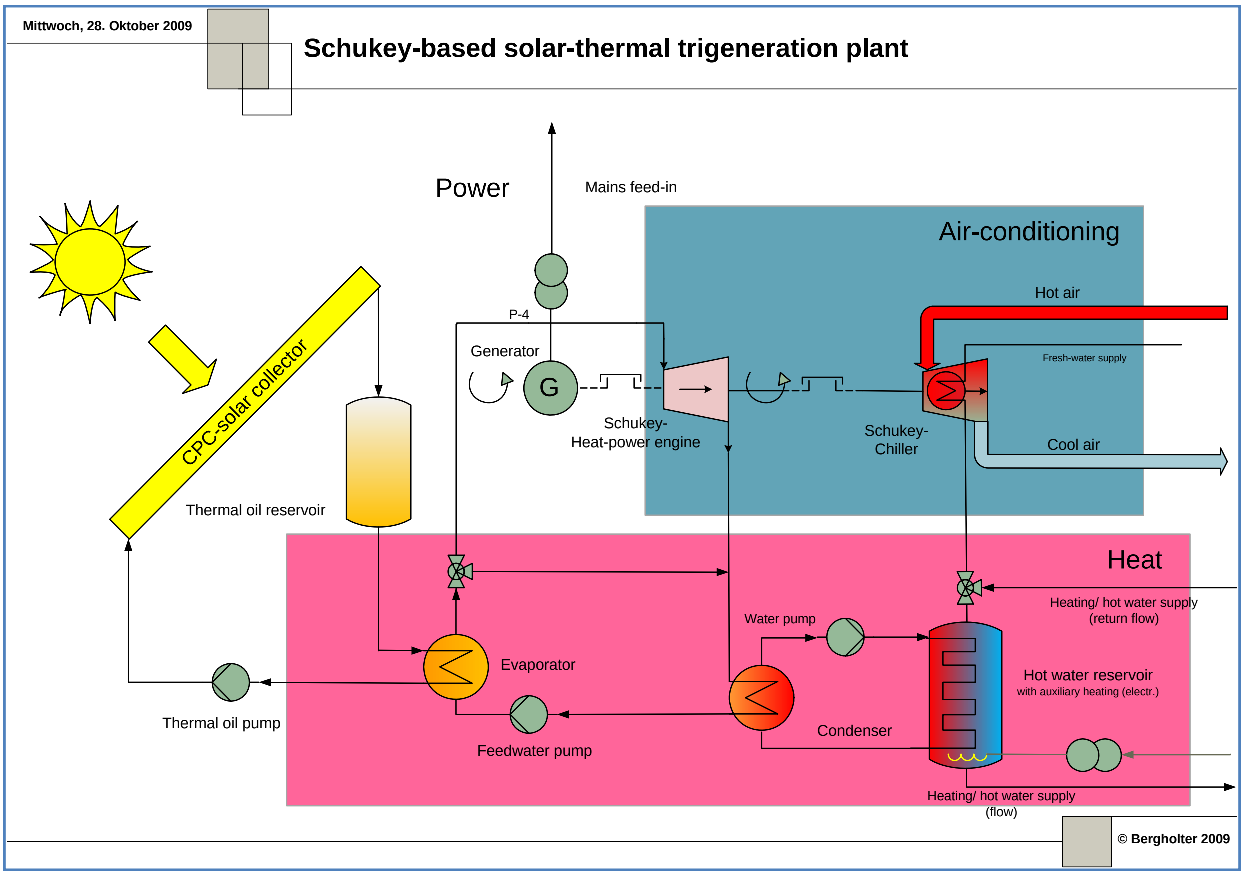


Fig. 5: Solar-thermal heat, power, and air-conditioning plant

produces process-related waste heat: in the third phase of the synthesis gas generation, occurring at a temperature of 1,000°C, a considerable amount of heat has to be supplied from outside.

(Fig. 4)

Whether, under the given operating conditions – i.e. feeding the generated electricity into the national grid and getting paid for it – an alternative refrigeration is profitable, will have to be determined in each individual case.

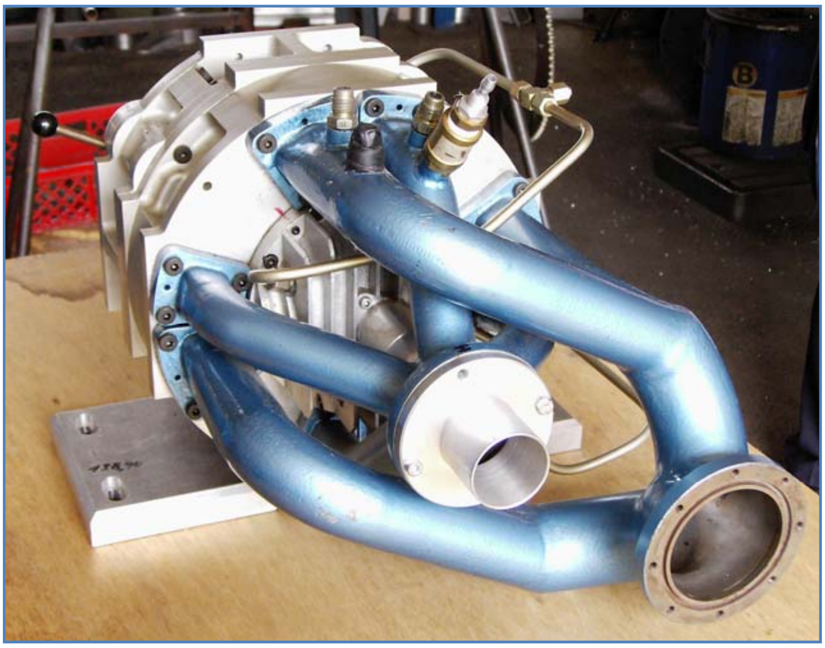


Fig. 6: Within the next six months, Thermodyna plans to build a pilot plant that generates electricity and cooling. The overall output should be sufficient to air-condition, for instance, filling station shops or restaurants with solar heat.

Two Schukey heat-power engines connected in series are used to recover energy. With that, the electrical efficiency of the plant increases from 27.5% to 37.5%. The overall efficiency rises from 82.5% to 92.5%.

Fig. 7: View into the interior of a Schukey engine. What can be seen are the two rotor-blade crosses (red and yellow). The two gear units are at the right and left ends. Each gear unit drives its respective rotor.

As an isolated application not connected to the grid and therefore not eligible for feed-in payments, this plant – instead of generating electricity – can deliver a theoretical refrigeration capacity of more than 1 MW.

Profitability

The ST can increase the electrical efficiency of a CHP plant by 12 to 40%, depending on the type and the waste heat available. With complete heat extraction, the ST can achieve overall efficiency rates of more that 90%. Particularly, smaller CHP plants with high energy recovery benefit from this increase.

The input values for the calculation model are based on an average CHP plant with synthesis-gas generation and a gas engine – electrical output without Schukey retrofitting: 275 kW, with Schukey retrofitting: 375 kW, annual hours of operation: 6,000. The Schukey chilling unit is optional. Costs for the generation of energy from wood chips: €110 per tonne. The calculation includes only the share of the power plant without the expenses and income from the heat extraction.

The most important results are:

- The electricity generation costs of the plant amount to about €0.15 per kWh without the ST and to about €0.12 per kWh with the ST.
- If the electricity is fed into the national grid against payment, the annual surplus with the ST amounts to approximately €120,000 – that is significantly more than the additional capital investment.
- The fuel costs are the main cost driver: in this case, they amount to more than 60% of the total costs. The rest is about equally shared between write-offs, imputed interest and operating costs.
- The costs of refrigeration (without distribution) are about €0.05 per kWh cooling output.

The low costs for refrigeration can basically be attributed to two factors:

(1) Due to the mechanical combination of electricity generation and refrigeration, the engine produces variable portions of electricity and cooling at the same time. If there is no need for refrigeration, the engine can generate electricity without limitation. Thus, every hour of operation is a full-load hour.

(2) The manufacture of the ST is generally easy and very low-cost. Furthermore, the ambient air is cooled directly in that it flows through the Schukey engine. This technol-

ogy is extremely simple, rugged, and inexpensive to purchase and run.

With the plant connected to the national grid and the feed-in payments exceeding the general supply costs, the generated electricity is always then fed in if the income from the feed-in is higher than that from the cooling output.

If cooling is needed locally, e.g. for air-conditioning purposes, it is usually best to make use of that possibility – whether in the case of an isolated application or a plant connected to the national grid without feed-in payments.

A Schukey trigeneration unit can always supply heat, power, and cooling as required.

Electricity and cooling from solar heat

Solar heat becomes more and more important also in the production of electricity.

Particularly, large power plant projects such as Nevada Solar One near Las Vegas or DESERTEC in Europe and North Africa are becoming a talking point. There is more than enough solar energy available anytime and free of charge. If we succeed in utilising it on a large scale, the energy problems of humankind will be solved once and for all.

Solar heat technology is simple, and its potential to lower costs is still high. Novel short-time storage technologies make possible the continued operation of the power plant even after sunset.

The projects implemented and planned to date are, without exception, large-scale power plants with an electrical output of several hundred MW. The technology used to convert heat into electricity requires very high temperatures of several hundred degrees Celsius. There are so far no plans to utilise combined heat and power and/or refrigeration. The energy demand of these large-scale power plants can be met profitably only in sunny regions.

But electricity and cooling can also be generated, even in our part of the world, with smaller solar heat units, if – as is the case with the Schukey technology – a conversion technology is available that operates profitably also at relatively low temperatures and with a varying energy input.

If, in addition, solar and waste heat are utilised, the result will be small decentralised trigeneration solutions that supply heat from solar energy free of charge.

The design of this plant – the solar-thermal heat, power, and air-conditioning plant – looks very much like that of the combined heat and power plant with refrigeration.

(Fig. 5)

Off-the-shelf evacuated tube collectors are generally suitable for the heat supply. If there is enough medium (steam) available, a collector area of 40 m² can generate an output of between 2.5 and 5 kW_{el}.

Depending on requirements, either electricity is fed into the grid or the Schukey technology is used to air-condition the building. Moreover, a solar heat plant of that size covers about 77% of the heat demand of an average single-family detached house.

Additional heating is necessary only for less than 2,000 kWh annually. If this is done with electricity, there is no need for a second heating system in addition to the solar heat.

Solar-thermal heat and power plants using the ST can be run profitably also in this (not so sunny) part of the world; in regions with higher insolation, the total energy demand including air-conditioning can be met.

Whereas, in our temperate zone, the electricity generation costs are similar to those for mains electricity, they can be cut approximately by half in regions with more sunshine.

Cooling from solar heat using the ST can also be produced at about half the cost of generating electricity.

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