SEWAGE WATER: INTERESTING HEAT SOURCE FOR HEAT PUMPS AND CHILLERS

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Abstract: Wastewater (sewage) is a source of energy which can be used for heating and cooling buildings with heat pumps. The technology is simple and proven. The first installations were built more than 20 years ago. Over 500 wastewater heat pumps are in operation world-wide. Thermal ratings range from 10 kW to 20 MW. Studies made in Switzerland and Germany show that 3% of all buildings could be supplied with heat (or cold) on the basis of wastewater. On account of the ideal source temperatures available (between 10°C and 25°C all year round), wastewater heat pumps attain high performance figures. In addition, such installations have an outstanding environmental performance.
In 1993, the Swiss Federal Office of Energy awarded the SwissEnergy Agency for Infrastructure Plants the task of developing and propagating the use of wastewater as a source of heating and cooling for buildings. As a result of the activities of this programme, Switzerland has actually taken on the role as a pioneer in the international field of wastewater heat recovery.

Key words: ***Wastewater, sewage system, sewage disposal plants, heat recovery heat exchangers, heat pumps, chillers, fouling factor***

1 INTRODUCTION

Over the last 30 years, enormous progress has been made world-wide in the insulation of buildings. In Switzerland, the demand for thermal energy for new buildings (space heating and hot water) sank by around 10% to 30% compared with 1980’s figures. This success is based primarily on a reduction of the transmission losses through the windows and the opaque parts of the building shell. Important progress has also been made concerning other forms of heat loss: flue gas losses through chimneys and heat losses associated with ventilation. Thanks to stronger regulations and technical developments, the majority of energy that was lost in this way can, today, be recovered.
The situation in the case of drains and sewers is different. Although for a conventional new building around 15% of the thermal energy provided to the building is lost, unused, via the sewage system (for a building in low-energy consumption design the amount is up to 30%!). Virtually no progress has been made in this area. This leads to the fact that, today, sewers represent the largest source of heat leakage in buildings. According to the projections of "SwissEnergy for Infrastructure Plants", approximately 6000 GWh of thermal energy are lost per annum in Switzerland alone via the sewage system. This corresponds to around 7% of the demand for thermal energy for space heating and hot water in Switzerland.
The Swiss Federal Office of Energy has set itself the goal of minimising these gigantic energy losses via the sewers as part of its sustainability strategy for the efficient use of energy and in accordance with national and international attempts and obligations concerning climate protection. For this reason, a program was started in Switzerland in the 1990s already on energy recuperation from waste water. The aim of this campaign, running under the name "SwissEnergy for Infrastructure Plants", is the systematic exploitation of the potential for

heating and cooling with wastewater. The following fields of action form the basis of the campaign:

- Support for research projects and technology development
- Support and accompainment of pilot and demonstration projects
- Development of instruments for the systematic assessment of the potential and for the appraisal of plant sites
- Promotion and execution of feasibility studies as a trigger for projects
- Provision of neutral advice for builders and local authorities
- Development of tools for designers and operators (see references)
- Development of quality assurance instruments for the planning and construction of installations
- Strategic assistance in the development of a market for wastewater energy plant

The following report presents a survey of the activities carried out, the findings won and the goals achieved.

2 WASTEWATER AS A SOURCE OF ENERGY

2.1 Characteristics (temperature, amount of water)

Compared with other, traditional sources of energy for heat pumps (groundwater, geothermal heat, outdoor air), wastewater from local residential drainage systems exhibits relatively high temperatures during the heating season. Values under 10°C are rare (Figure 1, left). Wastewater therefore offers an ideal basis for the use of heat. In summer, the wastewater temperatures climb to over 20°C. This also allows their use for the generation of cold for air-conditioning. In addition to these distinct annual characteristics, the temperature range of raw wastewater (before the sewage treatment plant) also shows variations in its daily and weekly characteristics. The daily variations are determined by the varying ratio of foul water. At night, with a low foul water fraction, the temperatures are typically 2 to 3 Kelvin lower than during the day. The variations during the week can be attributed to the weather influence. During rainy periods, the wastewater temperature normally drops by a few degrees. This only applies, however, to mixed water sewers. For cleansed water, (output of the sewage treatment plant) the daily and weekly variations are distinctly damped (Figure 1, right).

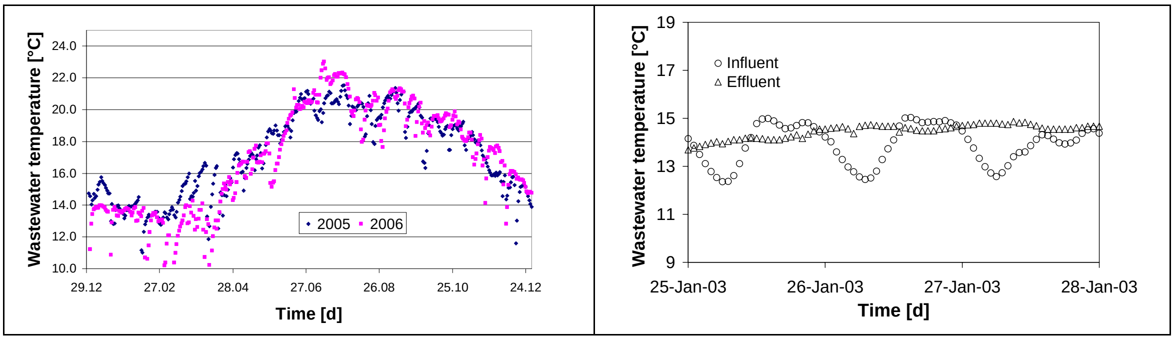

Figure 1: Left: Wastewater temperatures at the input of the sewage treatment plant in Zurich (yearly average). Right: Daily variations in the input and output. (EAWAG 2006).

The variations of the amount of wastewater are a second characteristic feature. In typical mixed-water sewage systems, the proportion of wastewater varies between the night minimum during dry weather and the maximum during strong rain by a factor of up to 10. Therefore, when planning and dimensioning wastewater energy installations, a careful definition of the amount of water is of greatest importance. Normally, the daily mean value during dry weather is taken as a basis and a reduction factor that takes account of daily variations is included. For the thermal use of wastewater within buildings, the wastewater flows in surges. Retention is therefore a precondition for a heat recovery.

2.2 Availability, potential

Wastewater is a finite source of energy. The amount available is dependent on the use of water in buildings. While the amount of water is increasing in countries with strong economic development and increasing standard of living, it is already sinking again in industrial nations as a result of efforts being made concerning the efficient use of water. When planning wastewater energy plants, the long-term development of wastewater quantities must therfore be carefully analysed.
In addition to the quantity, the local availability of wastewater as a source of energy is also limited. The possibilities for use that are economically interesting are concentrated at places where wastewater is available both continuously and in large quantities: Buildings with large quantities of wastewater (hospitals, industry, housing estates), the main drains of local settlements, sewage treatment plants.
In spite of these restrictions, the amount of energy available in wastewater is high. A study has shown that, in Switzerland alone, approximately 2 TWh of the heat used annually for space heating and the heating of water could be provided by wastewater (Hp. Eicher, 2008).

2.3 Possible uses

Wastewater is used on the one hand as a source of energy for heating and, on the other, for cooling. The use with a combined heating-refrigeration-machine is especially economically interesting. Energy from wastewater is normally used to cover of constant loads; conventional back-up systems are used to meet peak loads.
The use of wastewater energy can further be subdivided into three categories depending on where the energy is extracted: In-house energy recuperation, energy recovery from raw wastewater (sewers), energy recovery from cleansed wastewater after the sewage treatment plant (Figure 2).

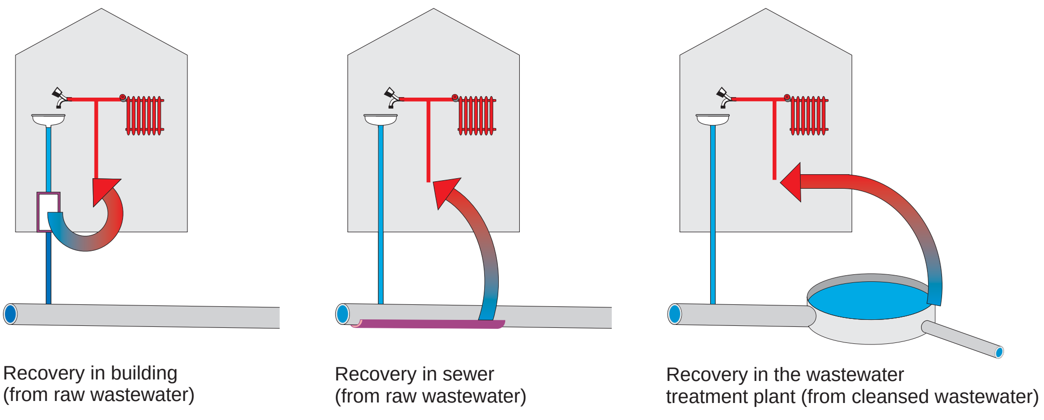

Figure 2: Possibilities for energy recovery from wastewater (SwissEnergy 2005)

3 IN-HOUSE HEAT RECOVERY

3.1 Systems

In-house, heat recovery from wastewater is practised in Switzerland in more than 200 installations: in industry, swimming pools, gymnasiums, hospitals and residential buildings. The use of wastewater energy in such in-house plants is concentrated on the heating-up of water. For installations with constant quantities of wastewater (industrial processes), tube-bundle heat exchangers that are operated according to the through-flow principle are normally used. In installations with non-constant wastewater flow, storage and filters systems with integrated spiral-tube heat exchangers are employed (Figure 3).

Figure 3: Wastewater collector with integrated heat exchanger. (Kalberer 2008).

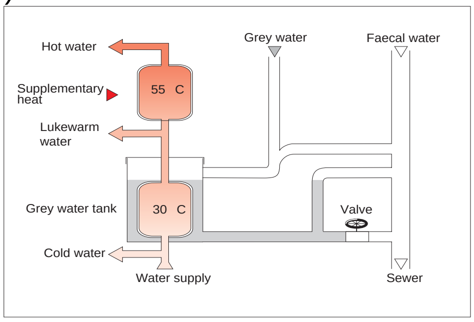

Figure 4: System for the heat recovery from wastewater in single-family homes.

As operational experiences from various installations show, the contamination of heat exchangers represents a great challenge to this method of wastewater heat use. There are plants which run with no problems and some which have had to be de-commissioned due to grave problems incurred. The quality of wastewater has a large influence on contamination. For this reason, such plants should only be implemented by experienced designers and system manufacturers. While in-house wastewater energy plants were mainly used in buildings with large quantities of wastewater up to now, systems for single-family homes are also currently being developed in Switzerland (Figure 4).

3.2 Example

A home for the elderly in Glarus (Switzerland), with 100 beds, was furnished with a central plant for wastewater heat recovery in 2004. The heat exchanger is located in a buried, external collection pit. Wastewater energy is used for the heating of water and hot-water circulation. The 30-kW heat pump achieves an annual coefficient of performance of 3.8 (measured) In spite of the high amount of contamination in the wastewater, the plant runs without problems. The cleaning of the heat exchanger has not been necessary up to now.

4 HEAT USE OF RAW WASTEWATER IN SEWERS

4.1 Preconditions

The most important precondition for the use of energy in raw wastewater is the approval of the operators of the sewers and the sewage treatment plant. It is a condition that the operation of the sewers and the sewage treatment plant is in no way impaired. From the point of view of the sewage treatment plant operator, the cooling down of the raw wastewater is a particularly delicate factor when extracting heat. The reason can be found in the fact that the efficiency of biological sewage treatment (nitrification) is temperature-dependent. If the wastewater temperature falls too much, the boundary values for pollutant concentration in the cleansed wastewater can no longer be guaranteed. For this reason, every wastewater treatment plant (WWTP) operator will only consent to the use of raw wastewater under particular conditions. Where wastewater temperatures are naturally already relatively low, the use of wastewater for heating purposes may possibly be refused completely.
The degree of cooling of the raw wastewater for the purpose of heat extraction must always be clarified by an expert. The decisive factor here is the design-temperature of the sewage treatment plant. In Switzerland, the cleansing process of many sewage treatment plants is designed for 10°C. For this reason, the Association of Swiss Wastewater and Water-protection experts VSA has, along with SwissEnergy, defined the following recommended

values for the thermal use of raw wastewater: The daily average wastewater temperature on entry to the sewage treatment plant should not be reduced to lower than 10°C. And the total cooling should, in total, be not more than 0.5 Kelvin (VSA 2004).

4.2 Technical possibilities

There are two different ways of recovering energy from sewers: the installation of a heat exchanger on the bed of the sewer or an external heat exchanger with an upstream pump and filter installation (figures 5 and 6). Examples of both variants have been in operation for more than 20 years (Bischofberger 1984).

In the first case, gutter-shaped heat exchanger elements made of stainless steel are used (Figure 7); these are hydraulically connected in a parallel or serial way via an intermediate circuit to a heat pump. Preconditions for this method of heat recovery are a sewer diameter of >800 mm, a quantity of water during dry weather of >30 l/s and a water-covered surface in the sewer bed of at least 0.8 m^2 per meter sewer length during dry weather.

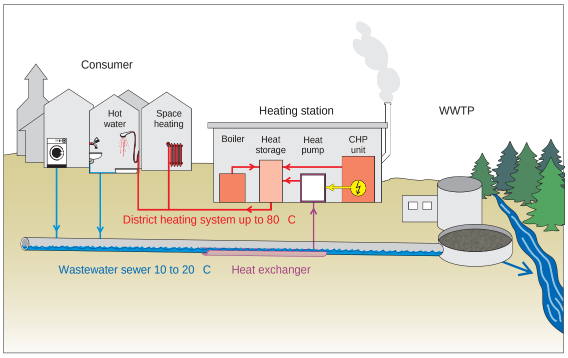

Figure 5: Using wastewater heat by means of gutter heat exchangers (SwissEnergy 2005).

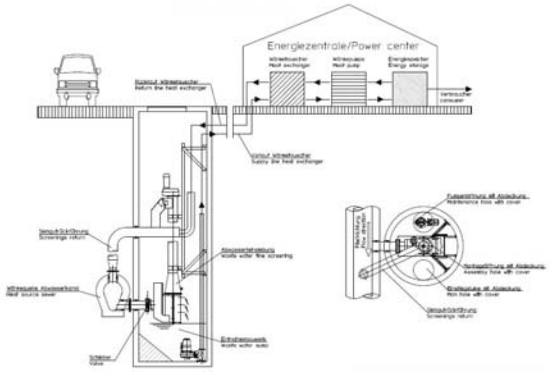

Figure 6: Sewer-external heat exchanger and upstream filtration (Huber 2007).

In the second variant, the raw wastewater is pumped through an aperture in the sewer bed, pre-cleaned in a sieve installation and then led either via an intermediate circuit to the heat exchanger or directly to the evaporator of the heat pump. For such applications, pipe-bundle or special plate heat exchangers are used.

Both systems for energy recovery from the sewage system have advantages and disadvantages. It must be decided on an individual basis which variant is better suited. Variant 1 with the gutter heat exchanger has the advantage of lower auxiliary power consumption. In addition, prefabricated concrete pipe elements with an integrated heat exchanger can be delivered ex-works and used for new sewage installations (Figure 8).

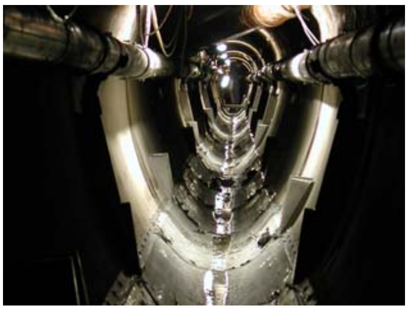

Figure 7: Gutter heat exchanger in a wastewater sewer (SwissEnergy 2005)

Figure 8: Sewer element with integrated heat exchanger (SwissEnergy 2005).

Higher technical flexibility speaks for variant 2. The cross-section and the slope of the sewer are unimportant; standardised products can be used. The installation during operation is much simpler than in the case of variant 1; drainage of the sewer is unnecessary. And the active surface area and the power of the heat exchanger are not limited by channel geometry. The largest plant of this kind in the world has a heat-transfer power of more than 50 MW. As in the in-house heat recovery system, the fouling-up of the heat exchangers also presents a challenge for the energetic use of raw wastewater. Problems can be avoided with expert planning and by the use of an intelligent operating strategy, (see section 10.1)

4.3 Examples of installations

4.3.1 Lucerne (Switzerland)

The head office of the Swiss Concordia health insurance company in Lucerne was furnished with a wastewater heating installation in 2007. Energy is won from a 60 m long town sewer using a gutter heat exchanger with a dry weather flow of 50 l/s. In addition to its heating energy needs in winter, the office building exhibits a continuous requirement for the cooling of EDP equipment. Also, the cooling of the offices causes peak demands in summer. The wastewater energy can therefore be used both for heating and for cooling (Figure 9). Surplus heat is transferred to a neighbouring hotel. The hotel has high heat requirements during the whole year for heating and the preparation of hot water. A gas-fired boiler is available for meeting peak demands in winter.

4.3.2 Oslo

In the Norwegian capital Oslo, a whole quarter has been supplied with wastewater energy for more than 20 years. An energy study in which different variants were compared for the supply of energy formed the starting point for planning. In the study, the lowest energy costs resulted for the variant that proposed the use of wastewater heat pumps. The reason for this lay in the combination of heating and cooling. Using a 4-pipe system, offices, schools, sports facilities and residential buildings connected to the system are supplied with both heat and cold for air-conditioning. As a result, decentralised air-conditioning plant and individual air-conditioning installations are not necessary. Investment and maintenance costs are lower. Energy supply is provided by three different centres. The base-load heating-power station with two heat pumps / refrigeration machines is located directly next to the wastewater sewer in a subterranean cavern (Figure 10). To cover peak loads, an existing heating central with 3 oil-fired boilers and a conventional refrigeration machine] is integrated in the energy network. The two wastewater heat pumps each with a power of 6.5 MW (refrigeration operation: 4.5 MW) supply 80% of the energy production.

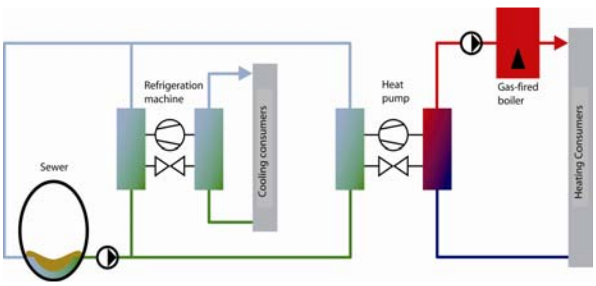

Figure 9: Schematic diagram of the wastewater energy installation in Lucerne (EBM 2007).

Figure 10: Sandvika Wastewater energy central in Oslo (Friotherm 2007).

5 THERMAL USE OF CLEANSED WASTEWATER

5.1 Potential

The energy potential of cleansed wastewater is much higher than that of raw wastewater. The reason for this lies in the fact that, downstream from the sewage treatment plant, the wastewater can be cooled down much more than upstream – by up to 8 Kelvin. For water fauna, such cooling of the wastewater is even desirable. Unfortunately, the large energy potential of cleansed wastewater can not be used in many locations because the sewage treatment plants are located outside residential areas, where no customers for the heat are available.

5.2 Heat use within the wastewater treatment plant

Ideally, the energy in cleansed wastewater can be used in the WWTP itself, e.g. for the heating of the digester tank or for low-temperature sludge drying. Both applications allow the use of wastewater energy at a temperature level that is interesting for heat pumps. There are, however, only few examples for the internal use of wastewater heat in WWTP. The reason for this lies in the fact that many WWTP have large amounts of waste heat at their disposal from the use of sewage gas in combined heat and power units. In future, the idea could meet with growing interest if larger WWTP increasingly condition their sewage gas to meet natural gas quality standards and thus would be able to feed it into the public gas mains.

5.3 Heat use external to the wastewater treatment plant

In Switzerland, there are 20 WWTP which use the heat of cleansed wastewater externally. It can be distinguished between two heat supply systems: cold and warm district heating (Figure 11). In the first case, cleansed wastewater is taken from the outflow of the sewage treatment plant and pumped via a cold main pipeline to the consumers. Heat generation using heat pumps occurs in de-centralised way. After heat has been extracted, the cooled-down wastewater is either returned to the sewage treatment plant or fed directly into a suitable stream or river (Deiss 2007). In the case of the warm district heating system, the usable heat is generated centrally at the sewage treatment plant or in a neighbouring building.

5.3.1 **Example in Berne (Switzerland)**

The WWTP of the Swiss capital is designed for approximately 350'000 inhabitants. In the cleansed wastewater, a potential for a heat recovery of more than 30 MW is available. A part of this potential (1400 kilowatt) is fed into a district heating system in the neighbouring quarter of Bremgarten (Figure 12). The Bremgarten heat collective sells a total of 5 GWh of heat per year. Around 60% of this originates from wastewater. On account of the considerable difference in height between the WWTP and the buyers of the heat, the network is divided into three sections with intermediary heat exchangers. The measured annual coefficient of performance of the wastewater heat pump system (including network pumps!) is 3.0.

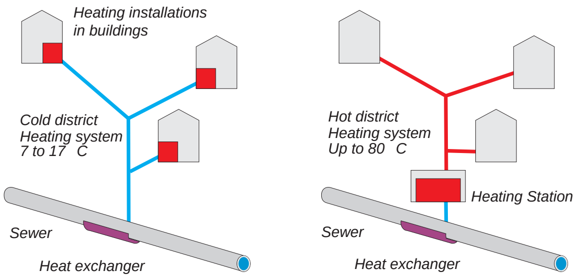

Figure 10: On the left cold district heating, on the right warm district heating.

Figure 11: Heat exchanger in the WWTP of Berne: Power: 2x 700 kilowatt. (Wellstein J. 2007)

6 COOLING WITH WASTEWATER

6.1 Synergies with the use for heating

Waste water can be used for heating and cooling. As numerous examples have shown, the combined use of wastewater for heat and cold normally provides an extremely economical supply of energy. Synergies result in the purchase of refrigerating machines and savings can be made when dimensioning back-up systems.

6.2 Direct or indirect cooling

Cooling with waste water is normally done using a traditional compression refrigerating machine. The direct use of cold wastewater is also possible, however, in cases where the wastewater temperature does not increase too strongly in summer. There exist examples of implementations for space cooling using wastewater in building-component conditioning.

6.3 Water protection aspects

If wastewater is used for cooling, the wastewater is heated up. At many locations, stipulations on water protection forbid the introduction of cooling water in streams and rivers. In such cases, the combined use of wastewater for heating and cooling is not possible. If cooling with wastewater is planned, the approval of the water protection authority responsible must first be sought.

7 ECONOMICS AND ECOLOGY

7.1 Economic viability

As a study made by the Swiss Federal Office of Energy shows, the economic viability of the use of heat from wastewater depends on three decisive factors: the prices for traditional sources of energy, the system size (heating power requirements) and the heat-density of its use (heat turnover in relation to line-length). For current oil prices of 90 $/100 l and a typical heat-density of 2.5 MWh per metre of distribution mains, the heat-demand boundary value for the economical operation of a wastewater energy plant is approximately 1 MW (Eicher Hp. 2008). This value applies to plants with bivalent energy supply with 60% to 80% of demands being met with heat pumps. If the plant is not only used for heating but also for cooling, the boundary value for heat demand drops considerably. As the study further shows, the costs of energy production in wastewater heating installations (including amortisation) lie in a wade range of 0.07 $ to 0.22 $ per kWh.

7.2 Efficiency

Wastewater heat pumps work efficiently. The consumption of primary energy in relation to the useful energy produced is lower by far than in the case of traditional systems for the generation of heat and cold. Compared with a condensing gas heater, a wastewater heat pump (with peak load boiler) uses 10% less primary energy, and compared with an oil-fired heater, even 23% less. Also, in comparison with other heat pump systems (groundwater, geothermal probes), wastewater installations perform well. The reason lies in the fact that the heat source exhibits favourable temperatures over the whole year. When correctly planned and optimally operated, wastewater systems achieve high annual coefficients of performance. The highest value measured in Switzerland at an installation in Basel is more than 7.

7.3 Environmental balance

Wastewater energy installations are environment-friendly. Compared to an oil-fired heating system, a bivalent wastewater heat pump that is powered mainly with electricity from Swiss power stations causes only 22% CO_2 emissions. If the power for the drive of the wastewater heat pump is provided by a gas-fuelled combined heat and power unit, emissions are reduced down to 41% (table 1). In an "Eco-balance of a heat pump with use of waste heat from raw wastewater" commissioned by the Building Office of the city of Zurich, the authors conclude that, for the total ecological evaluation, wastewater heat pumps perform better than natural gas-fired boilers by a factor of around 2 to 5 (Faist M. 2004).

Table 1: Relative CO_2 emissions of energy systems

Waste water heat pump, bivalent	22%
Combination heat pump - combined heat and power unit	41%
Gas heater with condensation	63%
Oil-fired heating	100%

Assumptions: Annual coefficient of performance of heat pump 3.5; heat production split: heat pump 80%, gas-fired peak-load boiler 20%, efficiency of the combined heat and power unit: power 35%, heat 55%; share of heat production: heat pump 50%, CHP unit 30%, gas-fired peak-load boiler 20% (EnergieSchweiz 2005).

8 SYSTEMATIC USE OF THE POTENTIAL

8.1 Potential assessment on the basis of drainage planning

In order to be able to use the energy in wastewater systematically, basic data is needed for designers and builders that show where and with which volume wastewater energy is available. Several Swiss cities have compiled so-called wastewater use maps, in which sewers suitable for heat extraction are marked and in which the usable power is noted. The collection and preparation of the data normally occurs within the framework of normal town planning operations (Schmid F. 2007).

8.2 Communal energy planning as a key instrument

Once collected, wastewater energy data can also be used for the regional planning of energy supplies. Various municipalities in Switzerland have a power supply plan which determines the priority of various sources of power in the various quarters. In addition to areas with gas supply and areas that allow the use of geothermal or groundwater heat, areas are also defined, which, on account of their proximity to a large sewer or the sewage treatment plant, are suitable for the use of wastewater energy (Figure 13). If construction occurs in such an area, the use of a wastewater heat pump is compulsory, provided that the plant can be operated in an economically justifiable way.

8.3 Local authorities as a driving force

Because the use of wastewater energy makes a contribution to the implementation of local objectives in the environmental and energy areas, numerous cities in Switzerland are active today in propagating this innovative technology. Possible activities are the financial support of preliminary investigations and implementation, the installation of wastewater energy plants in public buildings such as schools and offices, contracting of wastewater energy plants by public utilities or the provision of information for prospective builders within the framework of building approval procedures.

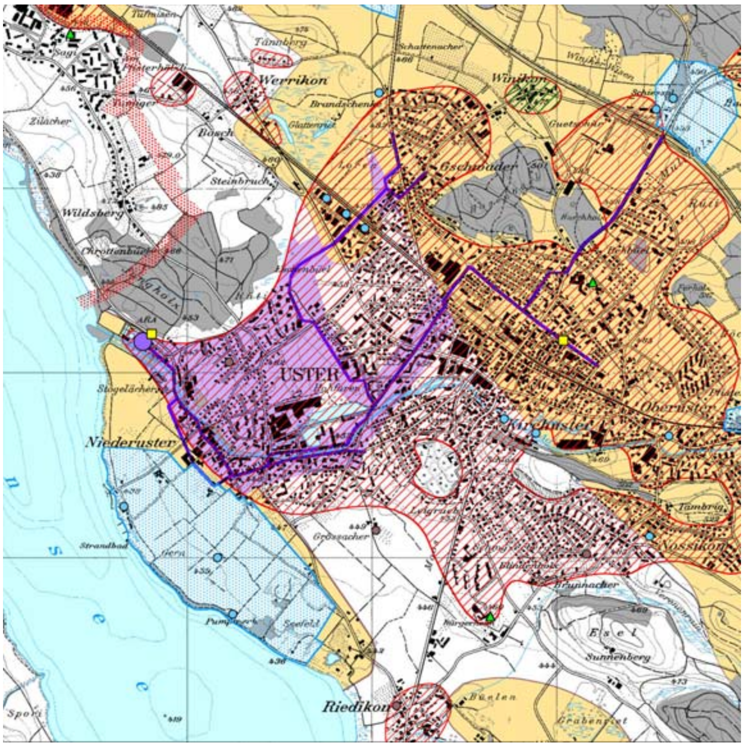

Figure 13: Energy supply plan of the City of Uster (Switzerland): The "Priority area for the use of wastewater energy" is shown in violet along the large drains and in the vicinity of the sewage treatment plant. The gas supply area is shown in shaded red. (SwissEnergy 2004)

9 LEGAL ASPECTS

Installations for the supply of energy using wastewater require, in addition to normal building approval, legal permission concerning the protection of streams and rivers. Additionally, An agreement with the operator of sewers and the sewage treatment plant on their use is also required. This can mean that a licence must be obtained.

9.1 Legal approval by water-protection authorities

The cooling down or heating-up of wastewater may not result in the WWTP no longer fulfilling its legal obligations; similarly the protection of streams and rivers must be guaranteed after energetically used wastewater is introduced. For this reason, legal approval is always demanded by the water-protection authority responsible. This authority decides on whether the planned cooling or warming of wastewater is justifiable.

9.2 Approval for use and licensing

All liabilities and responsibilities in connection with the building, operation and maintenance of installations for the generation of energy from wastewater are defined in an agreement for use between the owner of the WWTP and sewers and the user of the energy. In order to exclude any legal claims resulting from a shortfall in the energy delivery potential, the agreement for use normally binds the operator of the WWTP with a licence. It is generally agreed that the licence fee should be of merely symbolic character. A high fee would be disadvantageous for the economic viability of environment-friendly wastewater energy use.

10 NOTES ON PLANNING AND OPERATION

10.1 Dealing with the fouling of heat exchangers

The fouling of the heat exchangers can impair the efficiency of wastewater energy installations to a high degree. This fouling presents a great challenge to the planning and operation of wastewater energy installations. The formation of a biofilm on the surface of materials which come into contact with wastewater can, basically, never be completely excluded. In the worst case, the heat-transmission performance of a heat exchanger can be decreased by a factor of up to 2. Therefore, the question must be posed on how this phenomenon can be kept within controllable limits. Essentially, three strategies are available:

- Prevention of biofilm formation by primary treatment of wastewater (filtration, sieving), by the use of special materials and surfaces and through the optimisation of flow rates.
- Periodic cleaning of the heat exchanger.
- Enlargement of the heat exchanger surfaces.

Which of these three strategies leads to the best result must be individually clarified on the basis of the wastewater quality and other relevant conditions.

10.2 Conception and control of plants

The efficient operation of wastewater energy plants requires appropriate control strategies and an intelligent hydraulic concept in order to be able to optimally deal with the variations in the energy available (characteristics of the wastewater flow) and load changes in energy demand. The design and control of the primary circuit presents a particular challenge. One possibility for optimising is then available when wastewater can be fed directly into the evaporator of the heat pump in order to achieve higher evaporation temperatures. Generally, it can be said that the conception and control of wastewater energy plant is simpler when cleansed wastewater is used than for the use of raw waste water. When using raw wastewater, a special solution is then necessary, if the operator of the sewage treatment plant calls for the interruption of energy extraction as soon as the wastewater temperature falls below the design temperature of the sewage treatment plant.

10.3 Recommendations for planning and dimensioning

The planning and dimensioning of wastewater heat installations requires specific knowledge in the wastewater technology area. In particular, great caution is called for when the amount of wastewater and its temperature are determined as well as when the transmission performance of the heat exchanger is defined. The engagement of a specialised planner is always recommended. The German Association for Wastewater Economy, Sewage and Wastes (DWA) has announced a leaflet that is to be published in autumn 2008 which will supply advice on the planning of wastewater energy plants (DWA rules 2008).

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