Heat Recovery in Thermal Baths

Pinch Analysis Leads to Optimal Heat Pump Usage

*Pierre Krummenacher, Frederic Staine and
Daniel Favrat, Switzerland*

Pinch analysis is a powerful analysis and design methodology for the integration of thermal processes. Although originally developed for and applied to continuous industrial processes, pinch analysis can be equally beneficial when applied to buildings. In this article, the retrofit of a heat recovery scheme in a thermal bathing resort is discussed, with pinch analysis used to optimize the placement of a heat pump and the operating temperatures of the supply manifolds.

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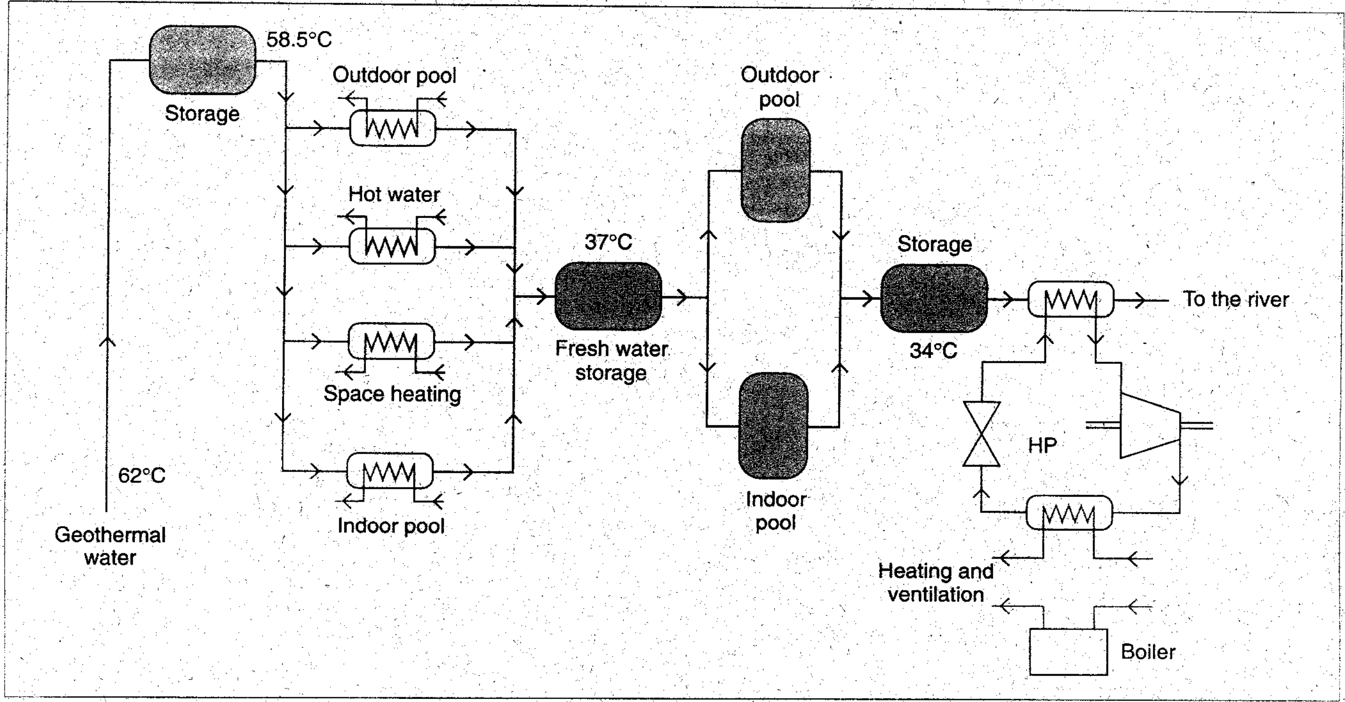
The thermal bathing resort at Lavey-les-Bains includes two swimming pools (indoor and outdoor), a health care facility, a hotel and a clinic. It was developed around a geothermal hot spring from a 201 m deep borehole dug in 1973. A simplified flow diagram of the system is shown in Figure 1.

The geothermal water is pumped at a rate varying between 200 l/min and 500 l/min and used to heat the swimming pool and tap water, and to supplement room heating. The cooled geothermal water capacity is used each night to replenish the outdoor and indoor swimming pools. The used swimming pool water is pumped into a buffer storage.

Heat Recovery

Up until 1983, only a small portion of heat from the used water, which is still lukewarm, was recovered by preheating tap water. Excess heat was lost in outdoor fountains before it was finally discharged in the nearby river Rhône at a maximum temperature of 28°C. In 1983, a heat pump was installed to recover more heat from the used water. The heat pump provides baseload space heating while the existing oil-fired boilers are only used for peak load at outside temperatures below 4°C. The heat pump has a 145 kWe electrically driven, reciprocating compressor working with CFC-12, an evaporation heat rate of 425 kW at 11°C and a condensation heat rate of 560 kW at about 60°C. Heat is presently distributed at two temperature levels (typically 70/50°C and 50/40°C, with the actual flow set-point temperature depending on the outdoor temperature). The seasonal performance factor (SPF) of the heat pump is 3.8.

Figure 1: Simplified flow diagram of the thermal bathing resort.



Unfortunately, the combination of increased power costs and low oil prices has meant that the operating costs of the heat pump are now more than 10% higher than those of the oil boiler. In addition, the tube bundle type heat exchangers perform poorly and are costly to maintain.

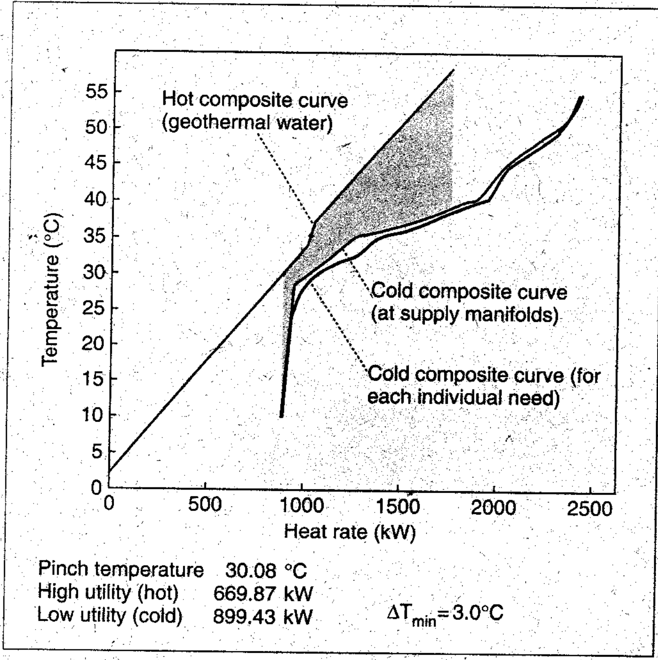
In order to improve this situation, a study has recently been started, with support from the Swiss Federal Office of Energy, to upgrade the performance of the heat recovery scheme. Taking a lead from work done for industrial processes, the study is applying the methodology of pinch analysis.

Pinch Analysis

Pinch analysis (also referred to as *pinch technology*) is a powerful analysis and design methodology for the integration of thermal processes (ranging from industrial processes to thermal energy systems in buildings, district heating, etc.). The ultimate goal is to design or retrofit existing processes to use as little primary energy as possible at minimum annual total cost. Pinch analysis provides the engineer with a systematic approach which leads quickly and with confidence to this goal by making the most out of the energy involved in the process. Intermediate steps include:

- determination of the minimum practical amount of energy required to operate the process;
- determination of the energy saving potential;
- examination of opportunities for process change;
- design of the heat exchanger network;
- optimization of the heat and cold supply system.

Figure 2: Composite curves for the original system.



Two graphical tools assist in this analysis, namely the composite curves and the grand composite curve. These curves show the temperature characteristics of the process considered, indicating the heating and/or cooling rates needed at each temperature. The pinch temperature derives from the composite curves and plays a central role for both the analysis and design phases, hence the name of this methodology. A general overview of pinch analysis can be found in [1].

Collecting the Data

Collecting data on the heating needs (cold streams) and heat recovery opportunities (hot streams) is an important step in pinch analysis. In buildings, as opposed to industrial processes, most of the heating needs can vary over a large range of heat rates as well as temperature levels throughout the year. In the study, heat streams were measured at outdoor temperatures of between -3°C and +7°C, and extrapolated to the lowest design temperature of -7°C for the purpose of pinch analysis.

The level at which a heating need is defined and assessed is important and depends on whether one is doing a retrofit or a completely new design. Take, for example, the stream associated with a heating need for space conditioning. When a new design is being considered, this will be defined as an air flow to be heated from the outdoor temperature to the prescribed temperature, since one still has the freedom to design the space conditioning unit and the heating coil. However, for a retrofit project for which modifications have to be minimized, the stream should be associated with the water flow supplying the existing heating coil which must be left unchanged. The cold stream should only be considered at the air flow level when the space conditioning unit is close to the end of its service life, or if the composite curve analysis proves that this unit acts as a single major limiting factor for heat recovery.

At the thermal bathing resort at Lavey-les-Bains, the existing heat exchangers are planned for replacement soon, so the associated heat streams have been measured on the secondary side (from a heat transfer point of view). In addition, each space heating and ventilation network has been individually monitored since measurements during cold days have shown that for many networks the temperatures at the inlet manifolds were significantly higher than the flow temperature, suggesting opportunities for lowering the inlet temperatures using an improved control system.

Composite Curves

The composite curves (at -7°C outdoor temperature) for the measured heat streams are shown in Figure 2. The hot composite represents the global heat recovery opportunity from the geothermal water (assuming it could be potentially cooled down to 2°C). The cold composite represents the numerous heat demands ncluding that for hot water, swimming pool water nd space heating via radiators, ventilators and underoor heating.

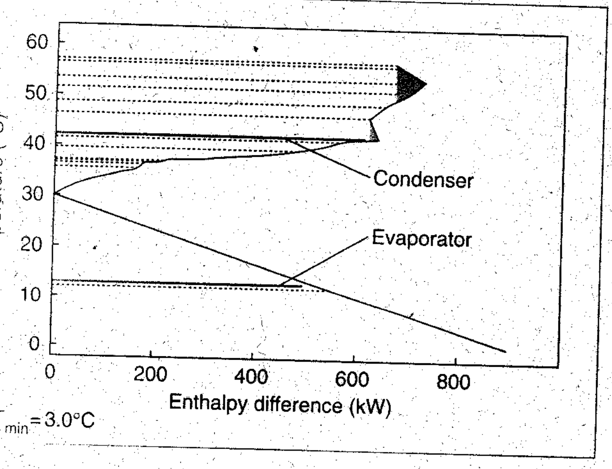
o illustrate the effect of supply manifold operating emperatures, two cold composite curves are drawn, ne using the complete stream data (a stream being ssociated with each single heating or cooling need) nd another where the manifold temperatures are djusted as closely as possible to the highest emperature requirement of the supplied heating etworks. The difference between a direct supply of ach single heating need and a supply through anifolds is in this case particularly important onsidering the fact that those streams occur in the itical pinch region.

om the composite curves, the particular streams ontributing significantly to the pinch point can be entified for retrofit.

perating in a better way

e grand composite curve (Figure 3) represents the inimum temperature levels of heat to be supplied by t utilities (above the pinch temperature of 30°C), as ell as the unused heat profile (below the pinch mperature). According to pinch analysis, the red nes represent temperature ranges that can be self tisfied. A heat pump is particularly well suited with ch temperature profiles. If a new heat pump was nsidered, it would ideally be of the Lorenz type eotropic mixture of refrigerants) or consist of two gle units in series. In this particular case, the study l probably confirm that the existing unit should be t, with an evaporation level adjusted to the highest tion pressure level tolerated by the compressor (to further investigated). Using HFC-134a as the rking fluid would result in the following calculated ues: 497 kW (11.4°C/4.4 bar) on the evaporator e, 591 kW (43°C/11.1 bar) on the condenser side, kWe to drive the compressor and a COP of 6.3 mpressor efficiency is assumed to be 70%).

re 3: The grand composite curve.



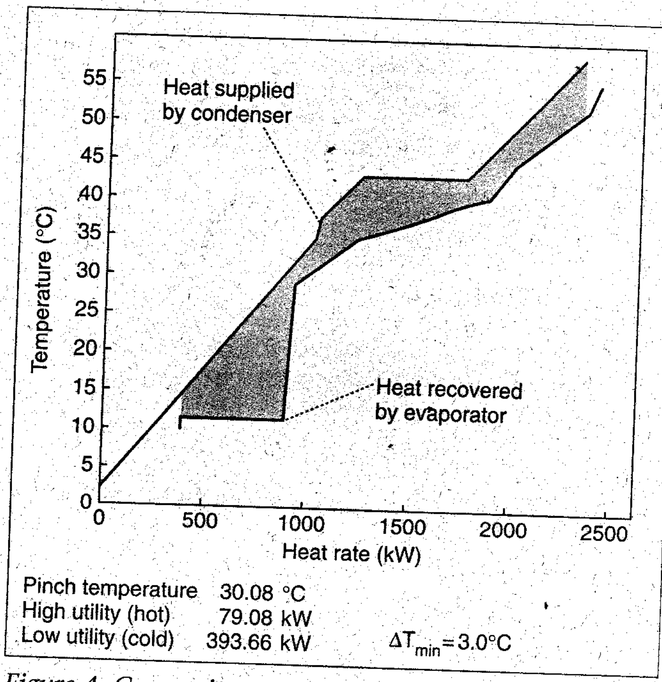


Figure 4: Composite curves with proposed heat pump.

Based on the proposed retrofit, Figure 4 shows the resulting composite curves including the heat pump streams. It can be seen that about 80 kW of heat must still be supplied. This could probably be met by a small increase in the pumping rate of the hot spring (the effect of such an increase has to be investigated) or by the existing back-up oil boiler. Calculations show that the heat rate supplied to the heat pump evaporator would practically drop to zero at outdoor temperatures above 7°C, corresponding to a mean yearly heat pump use of about 3600 hours.

Pointing the Way

The study shows how pinch analysis, initially developed for the energy integration of industrial processes, can significantly contribute to the design of energy recovery schemes in buildings. The study made at the thermal bathing resort has identified ways to improve the use of an existing heat pump and points the way to the further use of pinch analysis as a tool for optimizing waste heat recovery in buildings.

References:

[1] Linnhoff B., "Pinch Analysis - A State-of-the-Art Overview", TransIChemE, Vol. 71, Part A, pp. 503-522, September 1993.

[2] Krummenacher P., PinchLENI, "A User-Friendly Software Tool for Pinch Technology", CADDET Newsletter No 2/91, pp. 8-11.

Authors:

Mr Pierre Krummenacher, Mr Frederic Staine and Prof. Daniel Favrat
EPFL - LENI / DGM
CH-1015 Lausanne, Switzerland
Tel: +41-21-693-3516 Fax: +41-21-693-3502

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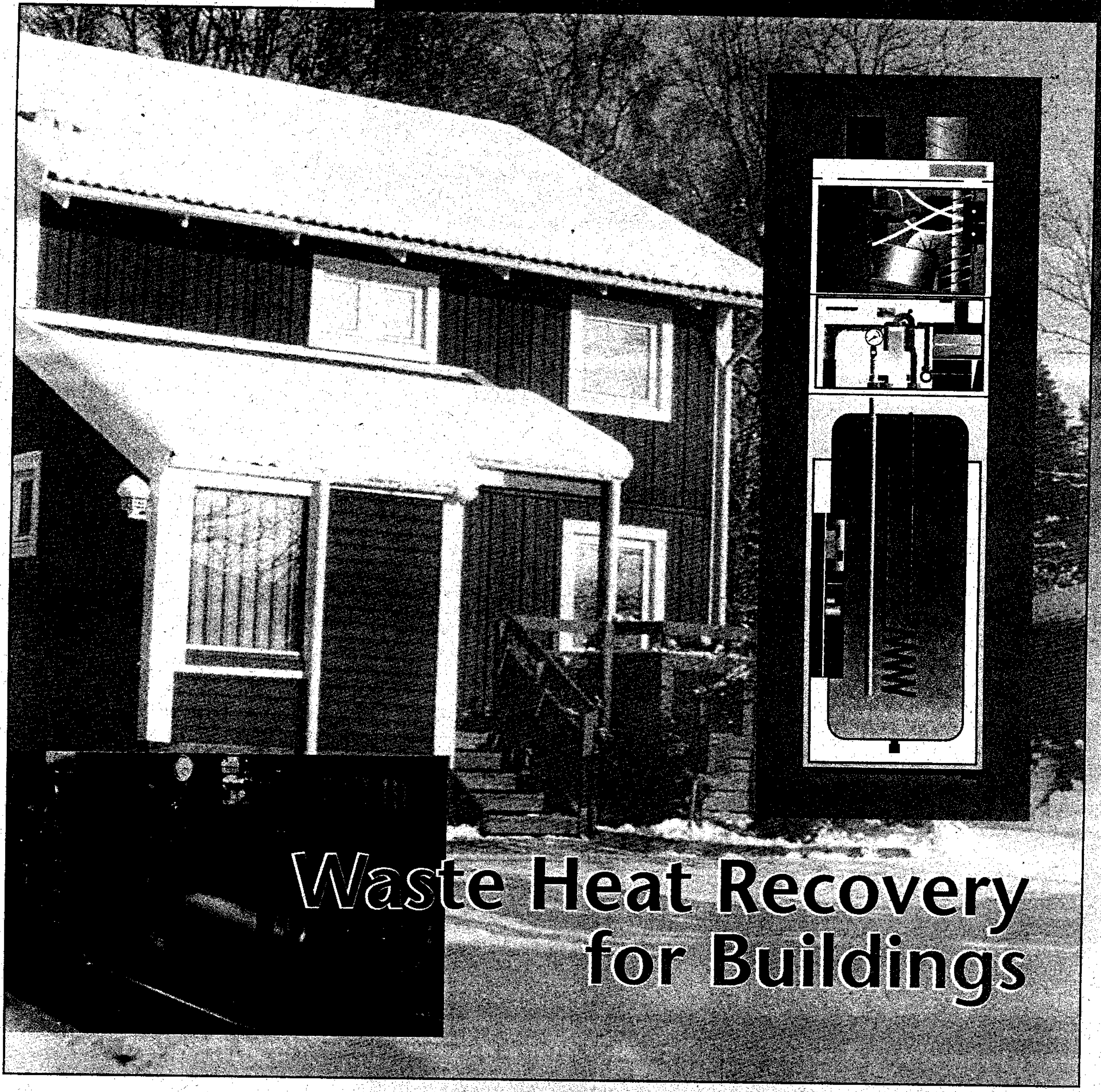

Waste Heat Recovery for Buildings