produces 8300 m³ of beer per year and had an energy consumption of about 6.5 GWh in 2004. More than 80% of the energy is supplied by natural gas. A steam boiler ($P = 2.6\ MW_{th}$) supplies heat to processes all over the factory.

The brewing process and the temperatures needed for the single process chains are shown schematically in figure 2.

Fig 1: Brewery: Cooker and bottle washing machine.

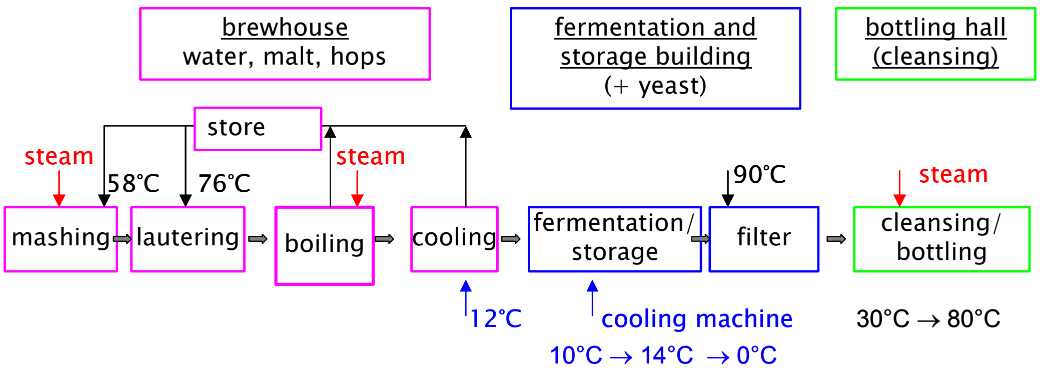

Fig. 2: Schematic of the brewing process

2.2 Energy supply

In order to investigate the energy consumption of the brewery, bills of power authorities, internal documentations, production logs, technical specifications of installations, as well as measurements of the steam flow rate and temperatures were evaluated. The resulting energy distribution in the brewery among different sectors and production chains is shown in figure 3:

• 31% of the energy is consumed in the brewhouse, due to the fact that a relatively old boiling procedure is used with a high energy consumption. By changing the boiling procedure, annual energy savings corresponding to 26 000 € could be achieved, based on the figures of the year 2004.

• 14% of the energy is consumed by the bottle washing machine. Since the machine is not insulated, a volume of about 19 m³ of alkaline solution cools down after each operation, that usually takes place in the morning at four days a week. Energy could be saved by changing the operation mode and by reducing the heat losses of the alkaline solution after operation.

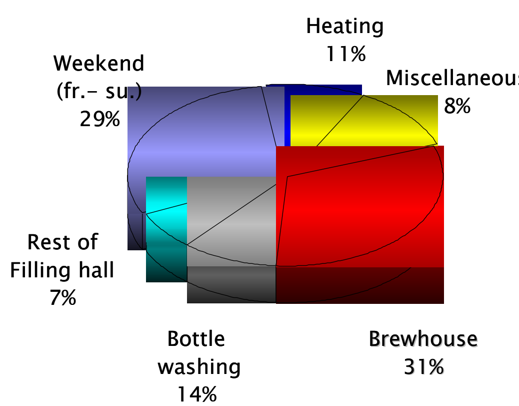

Fig. 3: Distribution of the heat consumption in the brewery.

• 29% of the energy demand occurs on the weekend, although no production takes place at that time. Even in the summer, the energy supply during a weekend is about 18 MWh, due to the fact that parts of the steam network and the condensate re-circulation loop are not insulated. As a matter of course the pipes should be insulated. The energy is used mainly to hold a high pressure in the steam cycle. With a new boiler control strategy and by lowering the pressure of the steam cycle from 7 to 4.5 bar during weekends, the number of burner starts and the burner operation time could be reduced. This leads to a reduction of the energy consumption of about 80% during the weekends. This corresponds to a payback time of less than one year.

2.3 Example measurement

An example measurement of the alkaline solution temperature in the bottle washing machine during a period of 10 days is shown in figure 6. The time step of the measurement was 5min. As shown in the figure, the temperature of the solution during operation is about 80°C. At night, the solution cools down to about 55°C, and during weekends, even nearly to ambient temperature.

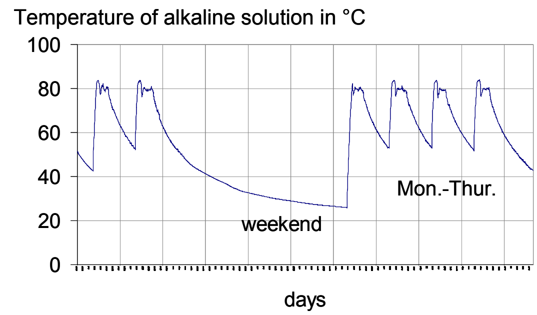

Fig. 6: Measured temperature of the alkaline solution in the bottle washing machine.

2.4 Integration of a solar heating system

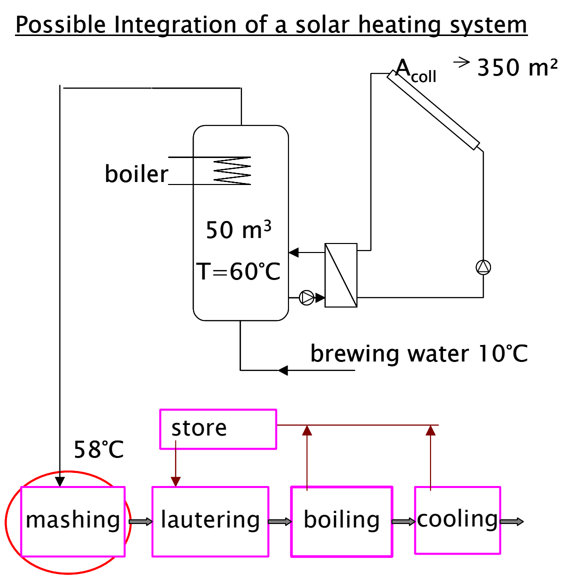

Fig. 4: Schematic of a solar assisted process heat generation in a brewery, heat supply for mashing

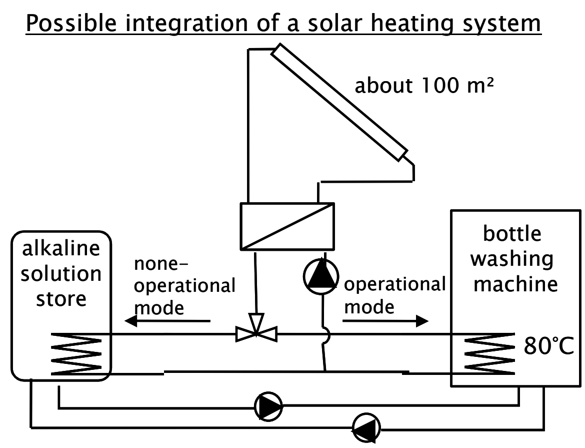

Fig. 5: Schematic of a solar plant for heating the alkaline solution of a bottle washing machine of the brewery investigated.

Solar process heat could well be integrated at two points into the process chain:

1.) In order to produce the wort, for mashing a high amount of water at a temperature of 58°C is needed. This can be provided at least partly by solar heat. With a water demand of 102 m³/week in the summer, a temperature lift of 50 K and a global irradiation in July of 150 kWh/m², a collector area of about 350 m² could be reasonable. Moreover, an existing 50 m³ heat store could be used. A schematic of a possible integration into a solar heating system is shown in figure 4.

With capital investment costs of 300 €/m_{coll}^2 (system costs), including subsidies, without VAT, it is possible to reach solar heat generation costs of approximately 6 €-cent/kWh with a (flat plate) solar collector area of 100 m².

2.) The heat necessary for the bottle washing machine could be reduced considerably, if an additional solar heated and well insulated sedimentation heat store was installed. The alkaline solution of the bottle washing machine could then be pumped into the heat store if the machine is not operating. In this way, the heat needed for starting the washing machine could be reduced significantly. Moreover, the installation of 100 to 200 m² vacuum tube collectors would be reasonable in order to heat the tank (figure 5).

It was estimated that 50% of the energy demand for heating up the alkaline solution after stand-by can be saved by use of a store and 100 m² collector area. With capital investment costs of 400 €/m_{coll}^2 (system costs), including subsidies, without VAT, it is possible to reach solar heat generation costs of approximately 6 to 7 ct/kWh with a collector area (vacuum tubes) of 100 m².

3. Integration of a Solar Heating System into the Industrial Process of a Laundry

3.1 Process chain

The laundry investigated is integrated in an institution for handicapped people and was built in 1995. The maximum washing capacity is about 1.2 tons per day. The main installations of the laundry are two normal washing machines (capacity: 35 kg and 80 kg), one continuous flow washing machine with five baths (capacity: 25 kg per bath), tumble driers and several finishing equipments like rotary and steam irons as well as smaller special installations.

Two pictures of the laundry are shown in figure 6. The laundry had a heat consumption of about 1.3 MWh in 2004, supplied by natural gas. The process heat is generated by a steam boiler (P_{max} = 1 MW_{th}), for the distribution a well insulated steam network and condensate re-circulation loop is installed. The water consumption in 2004 was about 9000 m³ and the main part (over 80%) was used for the washing machines. A simplified flowchart of the production process is shown in figure 7.

Fig 6: Laundry: Washing machine and finishing equipment.

3.2 Energy supply

To investigate the energy consumption of the laundry, it was possible to use detailed data from an internal energy management system. The natural gas and water consumption of the years 2002 to 2004 in a time scale of one week showed that about 80% of the water demand is used for the washing machines. Nevertheless, only 15% of the thermal energy is used for the washing process. The main part of the steam produced is used for the tumble driers and finishing installations.

The temperature range of the washing process is generally between 40°C and 70°C, in individual cases up to 90°C. To classify the heat demand of the several washing machines it was necessary to detect the program sequences, washing programmes and charges of the complete washing process. The results showed a weekly hot water demand of about 35 m³ with a temperature of 53°C (Q approx. 1600 kWh).

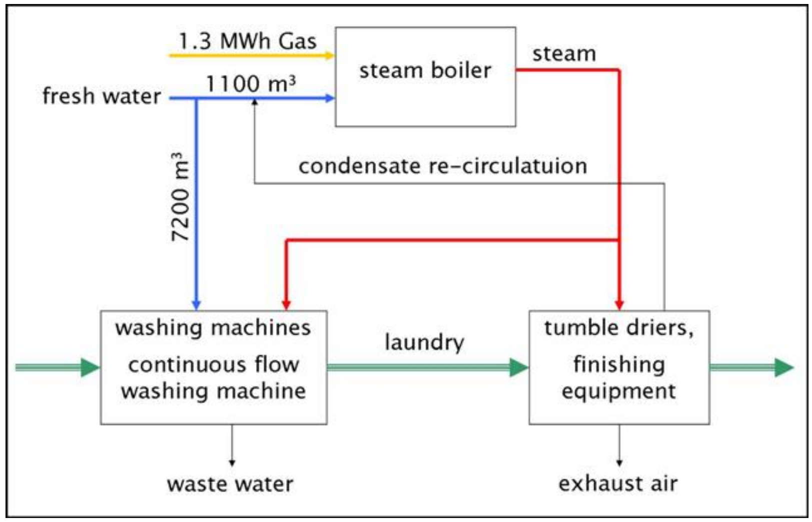

Fig 7: Simplified flowchart of the production process in the laundry

The energy saving potential in the heat supply systems is very low because all installations were planned and built in the mid nineties and are well insulated. Due to the fact that the laundry is part of an institution for handicapped people, there is no potential of rational processing.

3.3 Integration of a solar heating system

A possible system design is shown in figure 8, combining heat recovery and integration of solar process heat. The waste water that flows discontinuously from the washing machines could be collected in a small store (V < 1 m³) and pumped through a special heat exchanger for laundries. Thereby cold water could be heated up from 12°C to 24°C. The preheated water could be stored in an non-pressurised storage loaded additionally with solar energy.

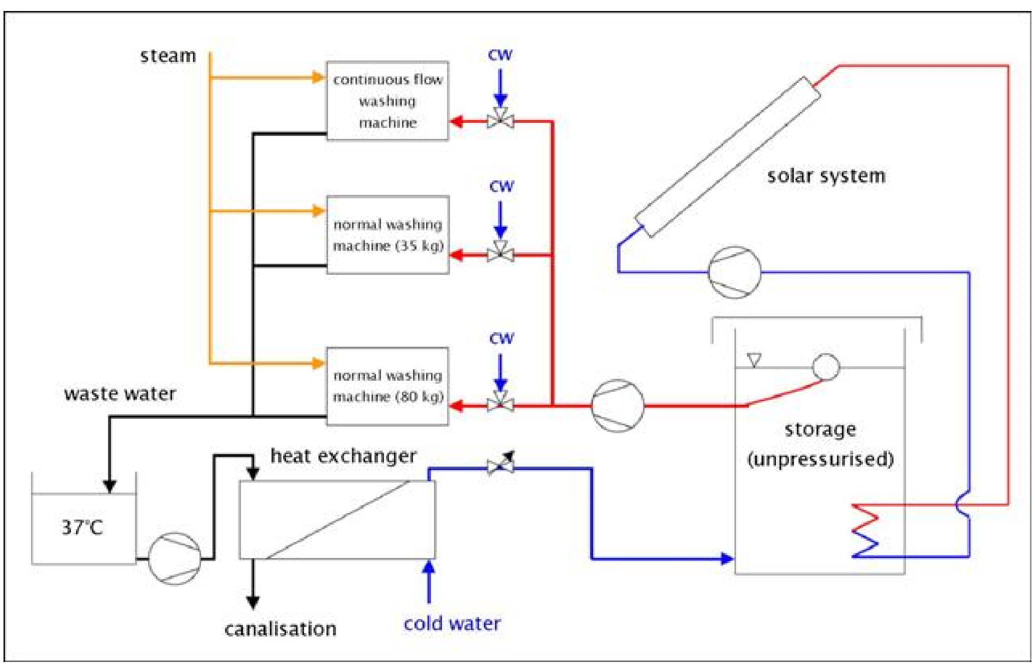

Fig. 8: Designed system concept for the laundry

An input-output analysis based on mass and energy balances (time scale 5 min.) showed a suitable collector surface of 100 m² in combination with a 2.5 m³ storage. Together with the heat recovery system a total fraction of nearly 70%, according to approx. 60 MWh/a was estimated.

With capital investment costs for the heat exchanger, the storage and system costs of 270 €/m_{coll}^2, including subsidies, without VAT, it is possible to reach solar heat generation costs of approximately 6 ct/kWh with a (flat plate) solar collector area of 100 m².

4. Saline and metal surface treatment

The results of the investigations regarding the saline showed also very low solar heat generation costs of about 6 ct/kWh for a collector surface of 75 m² and a storage with 1 m³. In this case the implementation of the solar heating system is very difficult, because the heat generation is accomplished by coal. Thereby the economic efficiency of the solar system is very difficult to realise.

Regarding the company dealing with metal surface treatment, only a few considerations were done. The investigation of the process chain showed a very suitable field of application for solar process heat. The company has several washers installed to clean their produced metallic components. These washers contains up to five baths with different temperature ranges. A solar heating system could be used to assist or ensure the heating of the baths.

5. Conclusion

For the industrial processes investigated, it was found that a more rational processing can be realized for example by means of heat recovery, by preventing unnecessary operation of the heat supply system, or a more steady and even process operation.

At the beginning of the analysis in some of the companies knowledge deficits about the own energy supply situation was discovered, especially concerning the distribution of the energy consumption among various users.

It was found that energy savings are possible in a wide range of capital spending and effort. Reasonable measures range from simple modifications of the boiler operation up to an extended change of the wort boiling process. Moreover, energy saving potentials can typically be conducted by insulating buildings, storages, and pipes, and by enhancing the hydraulic set up of the industrial process.

Due to high base loads only relatively small stores are necessary for an integration of solar heating systems to the industrial processes investigated. In some cases, already existing stores can be used for the solar heating systems. For collector areas of 100 m², it is possible to reach solar heat generation costs of approximately 6 €-cent/kWh.