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Energy conservation in the industry of Tanzania
Report 2: Cost reduction by energy conservation at Tanzania Breweries Ltd. : a case study

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Report 2:

Cost reduction by energy conservation at Tanzania Breweries Ltd.

a case study

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Executive summary

This research deals with energy conservation at Tanzania Breweries Ltd. (TBL). The problem definition is:

a) 'How can costs be reduced at Tanzania Breweries Ltd by energy conservation?' and
b) 'Which factors are influencing energy costs and what is their importance?'

Feasible energy cost reduction measures mean a reduction of production costs. This will increase the profitability and the market position of the company.

In most western literature on energy conservation ([Turner], [Witte], [Jacques],[Claus]) energy management practices are elaborated to control energy costs. One of the tools of energy management is an energy audit, a systematic way to assess the profitability of Energy Conservation Opportunities (ECO's). ECO's are technical and organizational alternatives in (or outside) a company or other organisation, which may lead to a reduction of energy consumption for this company.

A fish bone model has been set up to find all factors influencing (specific) energy costs. In a developing country, like Tanzania, other factors can play a role or the same factors can be more dominant in comparison with western countries. Appendix A gives an overview of the most important recognized factors. The influencing factors were divided in direct and indirect ones. The direct factors are the energy efficiency of the equipment, energy prices, capacity utilization, production losses, climate and production organisation. Examples of indirect factors are maintenance (influencing energy efficiency of equipment, capacity utilization and production losses) and spare part supply (influencing maintenance). Another distinction is the levels of the factors: level of production process, level of operators and mechanics, level of engineering and management and the level of external relations. When important factors influencing specific energy costs are on the level of external relations, energy costs may be difficult to control.

The stress in the research lies on the evaluation of energy conservation measures (problem definition a). The importance of factors influencing energy costs (problem definition b) is assessed only by mentioning some practical examples at TBL. With these examples an attempt will be made to demonstrate whether these factors do or do not influence energy cost and what the possibilities are to control these costs.

The supplied energy carriers at TBL are electricity, fuel oil and water. Specific electricity and fuel oil consumption (consumption per product of output) at TBL DSM is 2 up to 3 times higher then in western breweries. Specific water consumption is around 8 times higher. The cost percentage of energy is 23% of total direct production costs. At TBL specific energy costs are more than twice as high than for a western brewery with about the same yearly production. So cost saving by energy conservation seems to be very rewarding. Energy prices in Tanzania are lower than for a western brewery. When these prices would be the same, specific energy costs (including fuel oil, electricity and water costs) at TBL would be almost four times as high. Energy prices in Tanzania are not increasing when prices in US dollars are considered.

The most important cause of high specific energy consumption is a too low production capacity utilization. An increase of utilization from 30% in 1993 to 60% (a doubling of the production) causes approximately a 36% decrease of energy costs per crate of beer. Not only specific energy costs will reduce, but also specific overhead costs will decrease, resulting in higher specific profits. The main cause of the present low capacity utilization is down time, mainly by caused equipment break down. A reduction of total production losses from 16% (1993) to 8% saves about 8% of energy costs per crate of beer. Another important cause is lack of maintenance, which should be improved. Insufficient maintenance is the main cause of the low energy efficiency of the equipment, the low capacity utilization and high production losses. Influence of the climate would be much lower when good building maintenance would have been performed. Not enough research is done to know the exact causes of insufficient maintenance. Partly the cause is the difficulty to purchase the

appropriate spare parts and wrong priorities for foreign currency assignments. Surely maintenance and spare part supply has improved and will improve during the joint venture with South African Breweries. Other measures, on the area of improvement of used technologies and production organisation, can reduce energy costs with another 28%. All indicated measures can reduce energy costs with about 50%

Not all implementation costs and pay back periods could be assessed. For the measures, for which costs could be assessed, the average pay back period is 2 months. The average foreign currency component of quantified costs is about 75%. This percentage is quite high, but foreign currency requirements as a percentage of total energy cost savings is low (13%).

For a structural improvement of the controllability of energy (and other) costs on longer term, the following recommendations are important:

- improvement of maintenance and maintenance organisation of all sections;
- improvement of energy recording and purchase of energy recording equipment;
- appointment of full time energy manager;
- improvement of motivation of personnel.

About other indicated (indirect) factors influencing energy costs and the levels of factors no hard conclusions can be drawn, because not enough research could be done on these subjects.

For an overview of energy conservation opportunities and their profitabilities, see section 5.5 on page 70.

Preface

This report is a part of my final thesis to get the degree of Master of Science in International Technological Development Science at Eindhoven University of Technology. It deals with reduction of costs by energy conservation at Tanzania Breweries Ltd (TBL), Dar es Salaam, Tanzania (micro level). A second report for the same thesis has been written and deals about the importance of energy conservation in the Tanzanian industry (macro level). I stayed for about half a year in Dar es Salaam (November '93 until May '94) to collect the data for these reports.

Beside the mentioned research on macro and micro level, also on meso level (the beverage industry) a research was planned with a similar subject as on macro level. This part is cancelled, because data for this research segment was not available.

During the beginning of my stay in Tanzania it became clear that TBL was going to form a joint venture with South African Breweries (SAB). In December 1993 people from South Africa Breweries started working for TBL. I had my doubts about continuing the energy conservation research, because SAB had plans to refurbish the company. This would include, among many other things, a technical upgrading of the present production system. After consultation of the brewery management it was decided to go on with the research. According to the management it would be a welcome addition to their refurbishment.

At the moment the technical construction and implementation of the refurbishment has started. I hope and do think, that this report can contribute something to this refurbishment.

The problems I encountered in relation to the case study at TBL were:
- Lack of up to date decent drawings.
- Difficulty to get data from people. Information is very scattered and sometimes incorrect. Besides, a language barrier exists.
- Difficulty to quantify energy flows. Flow meters for oil consumption, steam consumption and partly for water consumption are not installed.
- Parameters are not stable. Process variables, like temperatures, quantities and process times are changing continuously.
- Since SAB has come, things are changing. I based this research on 1992 and 1993 data (e.g. production quantities). So this may give some conclusions about costs savings, which are not actual any more. In the first months of 1994, production has increased substantially.

I think it is impossible to make a detailed energy or mass balance for this brewery. Despite this constraint, still many useful energy conservation opportunities (ECO's) can be mentioned and checked for their profitabilities. Sometimes profitabilities cannot be quantified, because the exact savings or costs are not known.

Furthermore I would like to say that I enjoyed my stay in Tanzania and at Tanzania Breweries very much. Sometimes it was frustrating, but most of the time enjoyable and a valuable experience. My thanks go to Mr Kilewo, the managing director, and Mr Mwaimu, the director of man power development and administration, who made my stay at Tanzania Breweries Ltd possible. Furthermore I would like to thank Mr Griffith, the present brewery manager, and Mr Mwaipopo, the former brewery manager, for their support. Many thanks go to all employees of TBL who helped me in some kind of way or just greeted me (which must be everybody). Special thanks are for Mr L. Kobello, my supervisor at TBL. Many thanks also for the people of the engineering department of the Tanzania Industrial Research and Development Organisation (TIRDO) for their cooperation. They provided me with measuring equipment, support and useful information.

Dick Toussaint

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Glossary

- Abbreviations

DSM	Dar es Salaam
ECO	Energy Conservation Opportunity
ESMAP	Energy Sector Management Assistance Program
NUWA	National Urban Water Authority
SAB	South African Breweries Ltd.
SC (water)	Sand filtered and Chlorinated water
SD (water)	Sand filtered and Dechlorinated water
TANESCO	Tanzania Electric Supply Company
TBL	Tanzania Breweries Ltd.
TIRDO	Tanzania Industrial Research and Development Organisation
TSh	Tanzanian Shillings
US$	United States dollars

k	kilo =	1,000
M	Mega =	1,000,000
G	Giga =	1,000,000,000

kg	kilograms
l	litres
m	metres
yr	year
hr	hours
s	seconds
PSI	Pounds per Square Inch
PSIA	Pounds per Square Inch Absolute
PSIG	Pounds per Square Inch Gauge (absolute pressure - ambient pressure)
bar, bar abs.	
Pa	Pascal
J	Joules
W	Watts

- Conversion factors

1 kiloWatthour (kWh) =	3.6 MegaJoules (MJ) =	3.6 * 10^6 Joules
1 MegaWatthour (MWh) =	3.6 GigaJoules (GJ) =	3.6 * 10^9 Joules
1 bar =	14.7 Pounds per Square Inch (PSI) = 100 kPa	
1 gallon (UK) =	4.54 l	
1 inch =	2.54 cm = 0.0254 m	
1 US$ =	510 TSh (1/1/1994)	

1 Introduction

Energy consumption and energy conservation are hot items nowadays, with warnings about global temperature increase and exhaustion of fossil energy resources. The contribution of developing countries to the world energy consumption is still small, but should get increasing attention. More important factors for developing countries can be the heavy weight of oil imports on the balance of payment, discrepancies between energy demand and supply and the profitability of the individual companies.

This research deals with energy conservation at Tanzania Breweries Ltd. (TBL). The problem definition is:

a) 'How can costs be reduced at Tanzania Breweries Ltd by energy conservation?' and
b) 'Which factors are influencing energy costs and what is their importance?'

For TBL the possibilities of energy cost reduction are assessed. Feasible energy cost reduction measures mean a reduction of production costs. This will improve the profitability and the market position of the company.

This research is a part of a general research programme of the group International Technological Development Science at the Eindhoven University of Technology. The programme is entitled 'The industrialization process in the Third Word' [Cica]. In the period '93-'96 this means M.Sc. research has to contribute to an accumulation of knowledge on the industrialisation process in Tanzania, the Philippines and Costa Rica. The study in Tanzania will be in-depth and as far as possible complete. One of the spearpoint subjects of the programme is energy and its related problems.

The aim of the research programme is to identify the bottlenecks of progress in the industrialization process and to arrive at an improvement of governmental policies and development forecasts. This should lead to an overall improvement of development of Tanzania .

Chapter two is the framework for the way the energy conservation research is performed. The next chapter is a description of Tanzania Breweries Ltd. First the entire company is dealt with and later follows the Dar es Salaam plant, where the energy conservation research was performed. In chapter three the energy situation and related subjects of the Dar es Salaam plant is treated. In chapter four all energy conservation possibilities are evaluated. The last chapter contains conclusions and recommendations.

2 Theoretical framework

2.1 Definition of some terms related to energy conservation

In most western literature on energy conservation ([Turner], [Witte], [Jacques],[Claus]) energy management practices are elaborated to control energy costs. [Claus, p1] defines energy management as: 'Energy management is controlling energy flows according to a predetermined plan and in a systematic way with the aim of keeping present and future production costs as low as possible'. One of the tools is an energy audit. An energy audit is a systematic way to assess the profitability of Energy Conservation Opportunities (ECO's). ECO's are technical and organizational alternatives in (or outside) a company or other organisation, which may lead to a reduction of energy consumption for this company.

2.2 The energy audit

An energy audit has the following basic elements [Witte, p20]:

1. Historical review of energy-related records to establish a baseline against which progress can be measured.
2. Preplanning walk-through of the plant to identify major energy-using components
3. Detailed definition of data requirements with relation to
    - process flow sheets;
    - historical energy use and production data;
    - nameplate specifications of major energy-using equipment;
    - material properties: thermodynamics, physical properties and technical and economic feasibitity analyses;
    - dimensional data, e.g. pipe lengths and diameters, evaporation surfaces;
    - equipment operating profiles: operating hours and load fluctuations;
    - fuel and electricity costs;
4. Computation of mass and energy flows and estimation of losses;
5. Enumeration of energy conservation opportunities (ECO's);
6. Estimation of energy savings potential for each ECO;
7. Determination of cost and profitability potential for the implementation of ECO's;
8. Establishment of priority recommendations for ECO implementations;
9. Establishment of a continuous monitoring effort for major energy-using systems.

2.3 The energy model

The used energy model is displayed in figure 1. Since this report deals with energy conservation, the production process is considered as a part of the total energy system. The transformation process is the actual beer production process. The utilities are the services, which make the production process possible. In general they are centrally generated. These services consist of energy conversion equipment, which converts energy in a usable state, and central services. Energy conversion can be e.g. conversion of energy in fuel oil into steam and the conversion of electrical energy in cold refrigerant. Central services are management, administration, work shops, canteens and so on. The energy recovery system is the system in which energy is recovered to be used again. Primary energy carriers are the 'raw' energy supplies, like water, electrical energy and fuel oil. Converted energy will be used for central services and the production process. Recovered energy is leaded back to the storage facilities of the conversion system.

When energy flows in this model are quantified, flows are not discussed per block in the model but per energy subsystem. An energy subsystem is defined here as the combined system of energy conversion, energy distribution and energy consumption. For a refrigeration system this would mean the combination of the conversion of electrical energy into cold refrigerant, distribution of refrigerant and the cooled objects. This approach is used, because for each system a minimum of energy carriers is involved, resulting in less complication and fewer formulas.

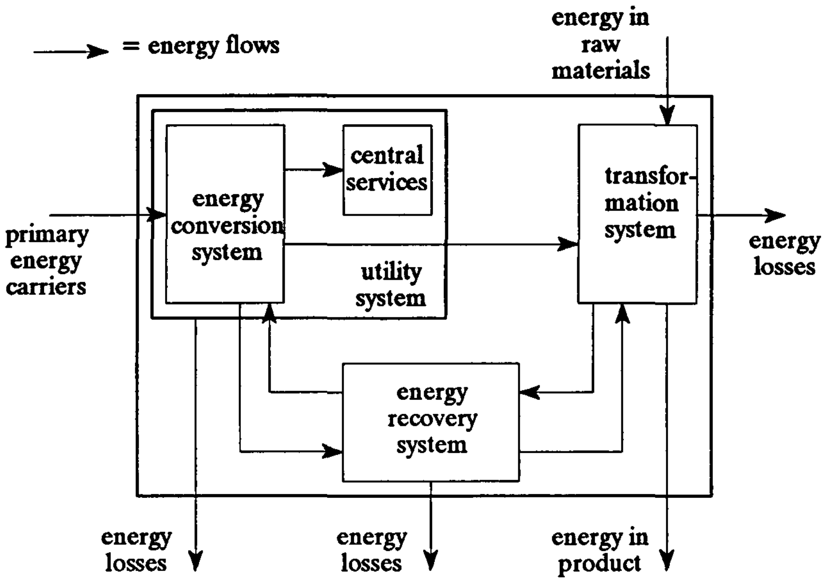


Fig. 1 The used energy model
Source: simplification of fig. 3.4 in Sustainable industrial production, an energy perspective by W.T.M. Wolters, 1994, page 35

2.4 Discussion of possible factors influencing energy costs

It is important to get an insight in the factors, which cause or influence the energy costs in a developing country. The enumeration of Energy Conservation Opportunities (ECO's) is a more or less arbitrary process. A guide for finding these ECO's can be the elaboration of the factors, which cause or influence energy costs and consumption. For western countries the literature mentioned in section 2.1 provides a guideline. In a developing country, like Tanzania, other factors can play a role or the same factors can be more dominant in comparison with western countries. Besides, for modern energy management practices with computer support, most developing countries are not ready yet.

For instance capacity utilization is a less dominant factor in western countries. Generally known is the fact that higher capacity utilization leads to a lower **specific energy consumption**. Specific energy consumption is energy consumption per unit of production output. This factor is more dominant in developing countries, because capacity utilization is usually lower in these countries. This effect is enforced by the fact that energy consumption is less flexible, because less advanced equipment and organization exist to control energy consumption.

Another example is maintenance and spare parts supply. Also in the previously mentioned literature, good maintenance of the production process and utility system is seen as an important factor to reduce energy costs. However, the spare parts needed to perform maintenance are supposed to be easily available. This is not always (or mostly not) the case in a country like Tanzania.

Another issue is the fact that, though advantages and possibilities for cost reduction by energy conservation may exist, a number of barriers hinder the introduction of these measures in developing countries. [Gamba] enumerates some barriers:

- technical barriers:
  - non-availability of suitable energy efficient equipment, energy measuring instrumentation and monitoring facilities;
  - lack of knowledge and technical expertise about possible energy conservation measures;
- economic barriers:
  - domestic energy prices below economic costs;
  - not using cost-price control systems for manufactured products;
- financial barriers:
  - limited availability of funds to carry out energy efficiency investments;
  - lack of simple, accessible medium term financing for energy efficient equipment changes;
- institutional and management barriers:
  - inadequate planning of decision making structure at plant, industry and national levels;
  - unfavourable legislation and regulations;
  - other national and industrial investment priorities;
  - lack of awareness of energy efficiency potential and its economics;
  - lack of engineering, audit and consulting support outside plants;
  - lack of energy management and engineering expertise in plants.

A fish bone model has been set up which includes a wider range of factors. When analysing the factors, direct and indirect ones can be distinguished. Figure 2 gives the direct factors.

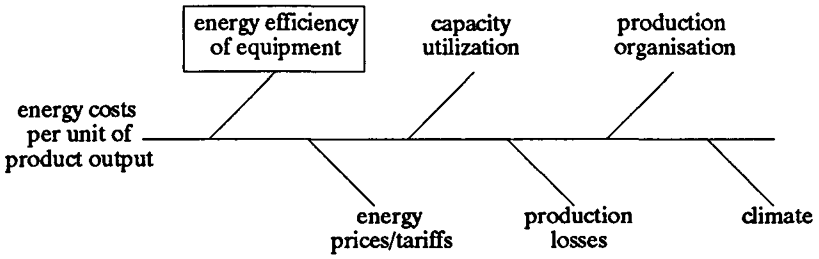


Fig. 2 Direct factors influencing energy costs

Most of these factors are caused again by other factors. For instance the factors determining 'energy efficiency equipment' (production process and utility system) are displayed in figure 3. Appendix A gives an overview for all recognized direct and indirect influencing factors. The intention has not been to be fully complete. Also a different ordering of factors is possible.

Comment is needed to explain the influence the recognized factors can have.

The recognized direct factors:

- Energy efficiency of production process and utility system

The energy efficiency of production process and utility system is the most important factor and determines the order of energy costs. Features playing a role are the used technologies, state of the equipment, quality of maintenance and the energy efficiency of operation.

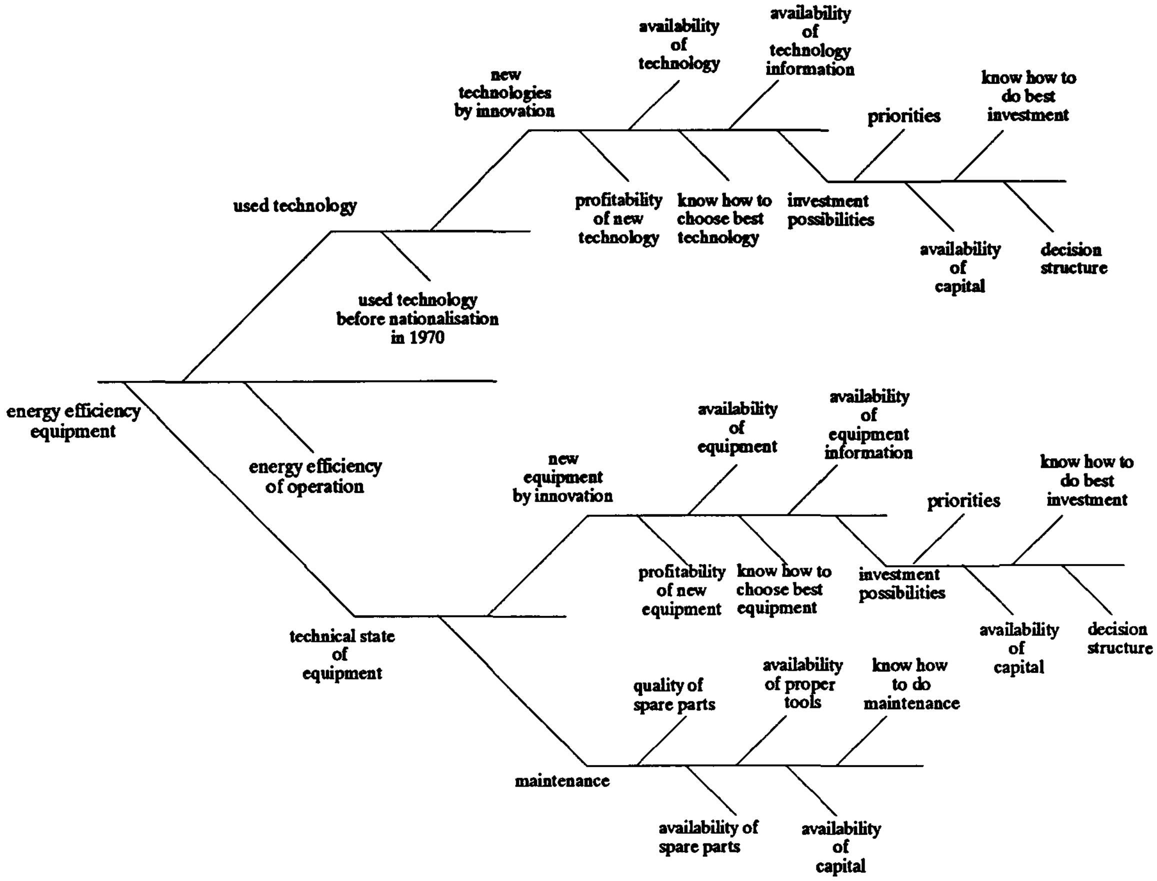


Fig. 3 Factors influencing the energy efficiency of the equipment

- Energy prices/tariffs

Of course energy prices determine the final energy costs directly. Indirectly low energy prices or certain tariff structures can be a demotivation for applying energy conservation measures.

- Capacity utilization

Higher capacity utilization leads to a lower specific energy consumption (energy consumption per unit of production output).

- Production losses

Also the production of losses consumes energy and therefore a higher loss percentage causes a higher energy consumption per sold product. Production loss is caused by indirect factors like quality of bottles (in case of a brewery) and the technical state of the production process.

- Production organisation

A good production organisation might reduce energy consumption, e.g.
- by well-organized logistics;
- by a better utilization of raw materials;
- by arranging good time schedules of equipment use, so that electricity costs will be lower (reducing peak demand charges);

- by energy management: recording of energy related data and taking necessary action when these data give reason for that.

- Climate

This factor is a special one in the list of direct factors, because it cannot be influenced by other (indirect) factors. Still it is an important factor. The hot and humid climate in Tanzania has a substantial effect on the electricity costs for refrigeration in comparison with western more moderate climates. Energy consumption will be higher. On the other hand, raw water which has to be heated up to a certain temperature will require less energy, because raw water temperatures are higher.

Indirect factors in the model:

- Used technologies

Applied technologies can be energy intensive or energy saving.

- Efficiency of operation

The energy efficiency of the equipment is also effected by the way the equipment is operated, e.g. switching off equipment when not used or choosing the best position of a valve controlling an energy flow.

- Maintenance

Maintenance is of vital importance. Lack of maintenance will cause higher production losses and a lower capacity utilization. Many energy losses occur because of lack of maintenance, e.g. maintenance of motor bearings, repair of leaks in steam and other pipe lines, repair of insulation and fouling of heat exchangers.

- Availability and quality of spare parts

Good maintenance can only be performed when enough spare parts of sufficient quality are available.

- Availability and quality of raw materials

Non-availability of raw materials will stop the production process and reduce capacity utilization. Bad quality of raw materials may increase production losses, e.g. easily breaking bottles, rejection of certain beer batches with bad quality, caused by bad quality of raw materials. A fluctuating quality of raw materials may cause fluctuating process variables, which makes process control more difficult.

- Beer consumption market

When not enough beer products can be sold, capacity utilization will decrease.

- Reliability of external energy supply and utilities

Power cuts may cause higher production losses because some beer batches may have to be drained because of the malfunctioning of the refrigeration equipment. Water shortage stops the entire beer bottling facilities. In the mean time beer has to be stored in a cold environment until water shortage is over. With respect to utilities the following example is given: when steam is not available or available at a low quality, the production process will stop or delay.

- Investment possibilities and priorities

Even when good energy measures are known, the capital to finance the measure has to be available. Also capital has to be available to perform maintenance. This accounts as well for reinvested profits as for external loans. Also the availability of foreign currencies is important when spare parts or other equipment have to be imported.

- Know-how

Know-how is important for almost every aspect of energy costs:
- know-how to organize the production process in an energy efficient way;
- know-how to use equipment in an energy efficient way;
- technical know-how to select and apply energy conservation measures;
- know-how to organize logistics (spare parts supply);
- know-how to control energy consumption and costs (energy management);
- know-how to organize and apply maintenance;
- know-how to select the best investments at the right time.

Other influencing factors

Some other factors do not have a close relation to any of the factors mentioned before, but have a general influence on the functioning of the production process and its energy costs. Here the factors 'motivation', 'corruption' and 'governmental energy policies and implementations' are mentioned.

- Motivation

When motivation is far from optimal, it has its reflections on the functioning of the production process. Low wages and corruption can demotivate the employees and make them more careless. Certain tasks, e.g. maintenance, will be performed less well and fast when people are not motivated.

- Corruption

Corruption has a retarding effect on the production process and its utilities. Corruption may have a negative influence on the available know how because the wrong people may be on the wrong positions. Corruption may also demotivate employees to do their job as well as possible. Low wages can cause nepotism.

- Govemmental energy policies and implementations

Energy policies might have the aim to improve the energy consumption pattern in industry. These policies can be implemented by e.g. subsidies for energy conservation measures, favourable import regulations for energy saving equipment. The government can also create an infrastructure for energy technology information, borrowing of energy measuring equipment, etc.

Levels of factors

The factors can also be distinguished by their level of origin. Distinguished levels are:
- the level of the production process itself (level 1);
- the level of operators and mechanics (level 2);
- the level of management and engineering (level 3);
- external relations (level 4).

In figure 4 all factors are displayed on their level of origin. Quite a few factors have their origin outside the company. When the influence of these factors is dominant, it may be very difficult to control energy costs within the company.

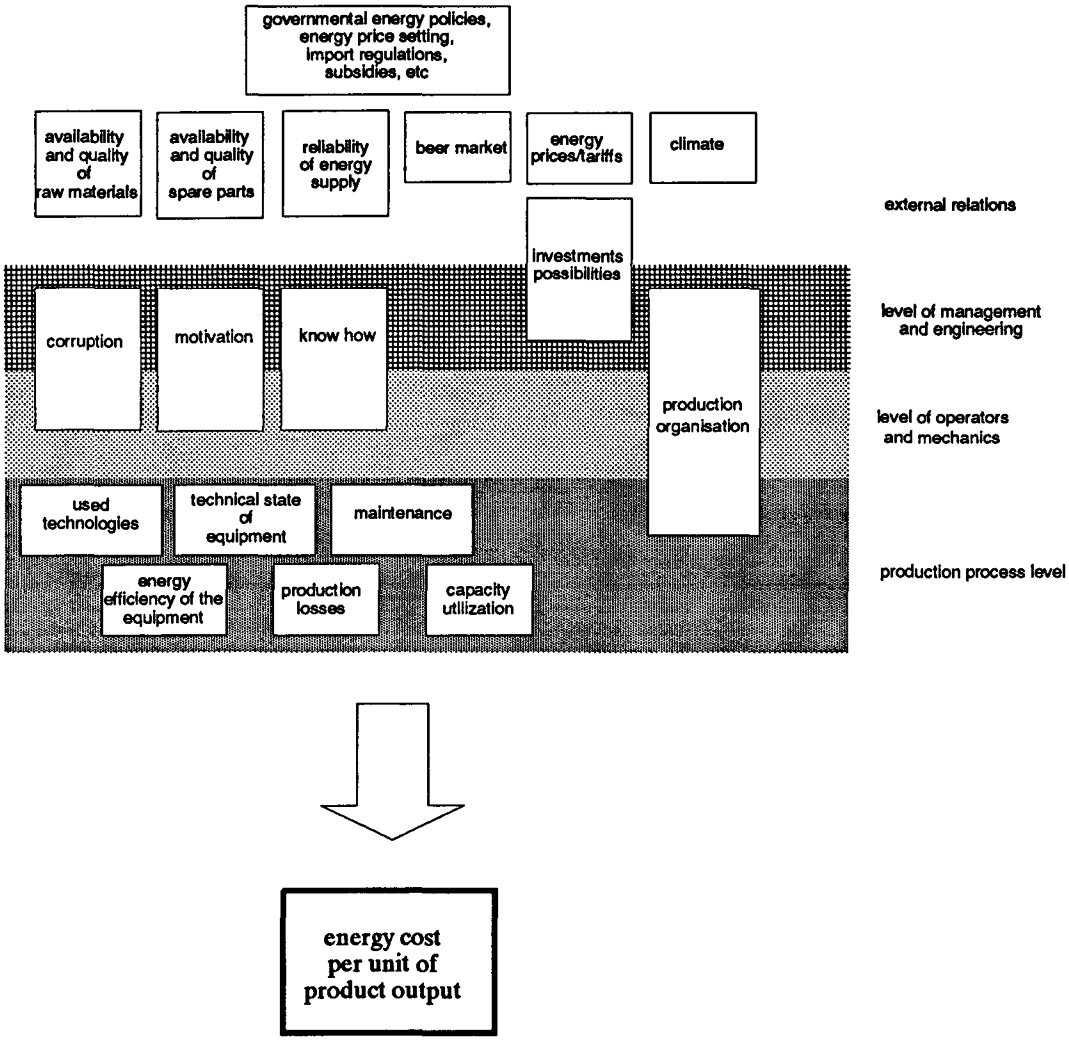


Fig. 4 Factors influencing energy costs on different levels

2.5 Scope of the research

The stress in this research lies on elaboration of energy conservation opportunities by an improved technical energy efficiency of the production process (e.g. by better maintenance, new technologies), higher capacity utilization, less production losses, and a better production organization.

In this research it is not intended to research and quantify the influence of all other mentioned factors in practice. Only by some practical examples from the situation at TBL and its external relations it will be demonstrated wether these factors do or do not influence energy costs and what the possibilities are to control these costs.

In developing countries the investment possibilities are usually low. Besides, the priority of investments for energy conservation is often low. The availability of foreign currencies to import equipment is also restricted. Therefore accent is laid on ECO's with high profitability, low investment needs with a small foreign currency component and a short pay back period.

An attempt will be made to get an idea of the contribution of different causes that influence energy costs at TBL in comparison with western breweries. These causes are the energy efficiency of the production process and utility system, capacity utilization, production losses, production organisation, energy prices and climate, i.e. the direct factors.

3 Description of Tanzania Breweries Ltd

3.1 History

The Dar es Salaam brewery was established in 1933. It was owned by East African Breweries, a company with English management. They also owned a brewery in Nairobi, Kenya. In 1966 a new brewery was commissioned in Dar es Salaam on the same site. In 1970 the company was nationalized and became Tanzania Breweries Ltd (TBL), together with a brewery in Arusha. Later a bottling plant was built in Moshi. Also farms were established to cultivate barley and a factory was built in Moshi to make malt out of this barley. In 1984 and 1991 the production capacity of the brewing and bottling facilities were increased in the Dar es Salaam plant.

3.2 The joint venture between Tanzania Breweries Ltd and South African Breweries

Since the eighties the company did less well. The production process degraded more and more, mainly because of old equipment and insufficient maintenance. The liberalization of the economy in 1985 caused new competition from imported beers. In the beginning of the nineties the management was looking for a foreign partner to cope with the problems. In November 1993 a joint venture was founded by the Government of Tanzania and Indol International, holding equal amounts of shares. Indol is a Dutch investment organisation and the owner of South Africa Breweries (SAB). SAB is the party which is directly involved in the management of TBL.

The goals of the new management of TBL to be fulfilled first are improvement of customer service, improvement of product quality and availability and reducing production costs. This is implemented by a two year refurbishment, which will last until the end of '95. This refurbishment includes upgrading of the production process, utilities and civil works. Also training of personnel is included, local training as well as training in South Africa.

On the longer term TBL wants to expand its market, first in Tanzania, and later TBL wants to become a leader in the East African beer market.

3.3 Company features

At the moment, TBL consists of two plants in operation, situated in Dar es Salaam and Arusha. A general head office is situated next to the brewery in Dar es Salaam. Malt from the factory in Moshi was found to be of inferior quality and at the moment the malt is imported from Belgium. The bottling plant in Moshi has been closed down. A new brewery is under construction in Mwanza, which is expected to be in production towards the end of 1995.

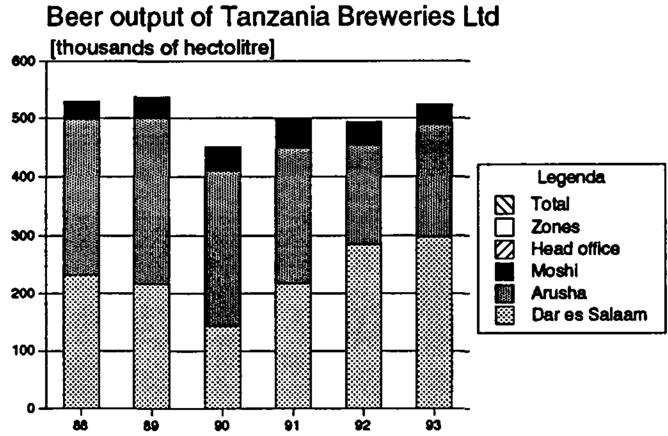


Fig. 5a Beer production at TBL
Source: [TBL1,2,3]

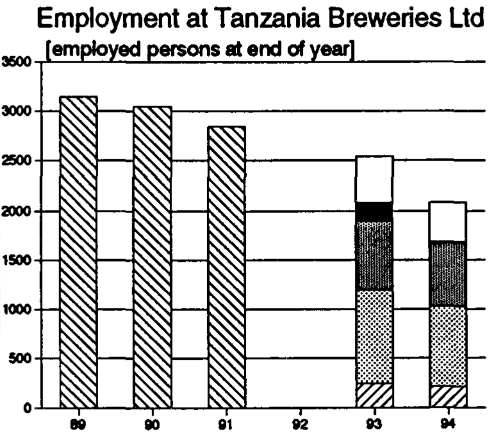


Fig. 5b Employment at TBL

Besides the main product Safari Lager (1993: 88%), also Pilsner Lager (11%) and Guinness (1%) have been produced. At present TBL is the only beer making company in Tanzania. It does not export any beer. At the moment a German company is building a brewery in Dar es Salaam. New locally owned breweries are being built in Dodoma and the Kilimanjaro region. So more local competition can be expected in the coming years.

Fig. 5a and b give the production and number of employees for the last years. In appendix B the TBL organisation structure is displayed, first the organisation before the joint venture with SAB, the second after.

3.4 Description of the DSM plant

The plant will be described within the frame of the energy model presented in section 2.3 of the previous chapter. In the next sections first the production process, the utility system and the energy recovery system will be described separately. The last part will show how all these parts are interconnected.

3.4.1 The production process

The beer production process exists of two main parts: the actual brewing section and the bottling section. The brewing section can be divided into six sections as shown in figure 6.

Appendix C2 presents a more detailed production process as applied at TBL Dar Es Salaam.

- Malt processing

During malt processing malt from the storage silo's is screened, milled and batched.

- Mash processing

The prepared malt is mixed with hot water of 50°C (mash water) in the mash vessel. At this temperature enzymes are active which convert insoluble proteins into soluble ones. After a specific amount of time temperature is raised to 68°C by indirect heating with steam. At this temperature other enzymes convert starch into malt sugars. Again after a certain amount of time temperature is raised to 78°C. At this temperature all active enzymes are destroyed. Then the mash enters a filter (lauter tun/ strain master), where spent grains are separated from the mixture. Extra water of 78°C (sparging water) is flushed through the spent grains in order to flush all sugars and aroma into the remaining mixture. Spent grains are drained and sold as cattle feed.

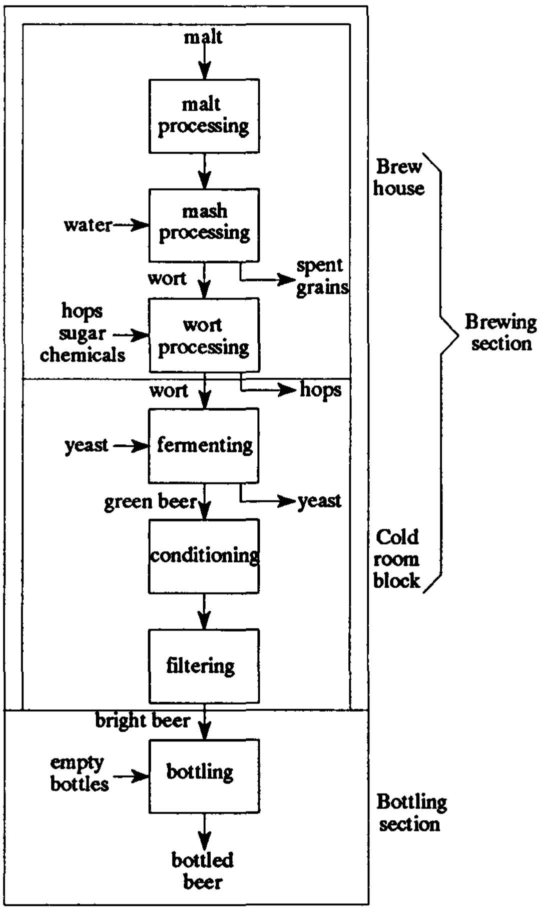


Fig. 6 The production of bottled beer at TBL

- Wort processing

The remaining mixture after mash processing is called wort. From the filter wort flows into the wort kettle or, when this vessel is occupied, into the wort receiver. In the wort kettle the wort is heated to 100°C and then boiled. This may take one up to three hours, depending on the gravity of the initial wort. During boiling hops, extra sugar and some flavour extracts are added. After boiling the wort is pumped to a whirlpool. Here hops are separated again. From the whirlpool the wort is pumped to the wort cooler (paraflow). Wort is cooled down to 10°C and transferred to the fermenting section.

- Fermenting

For fermentation yeast is added to the wort. In a biochemical process, initiated by the yeast, malt and other sugars are converted into alcohol and CO_2. A part of the CO_2 is collected and stored in liquid state for later injection during conditioning and before beer filtering. During the reaction mentioned above heat is released. The mixture is kept at the same temperature by use of vessels, which are cooled by refrigerant circulation through so-called vessel jackets. This process takes about 10 days. When fermentation is completed, yeast is separated from the mixture, which is now called green beer.

- Conditioning

After fermentation the beer is cooled down in the fermenting vessels to about 2°C and transferred to the conditioning tanks. Now the conditioning or lagering has started. During this step the beer ripens and gets full taste. This takes about two weeks in average. The beer is kept cool in vessels, which are installed in air cooled rooms.

- Filtering

First of all the beer, which has gained some heat during conditioning, is cooled down again to about 1°C. Then CO_2 is injected into the beer. Hereafter, beer is filtered to remove remaining yeast and other insoluble matters. After filtering the beer is bright and stored in bright beer tanks, ready to go to the bottling halls.

- Bottling

After brewing the beer has to be bottled. The bottling lines consist of the following parts:
- unpacker: takes out the bottles of the crates;
- bottle washer: washes bottles;
- crate washer: washes crates;
- filler: fills bottles with beer;
- pasteurizer: pasteurizes beer, so that the activities of microbes and possible remaining yeast will be stopped;
- labeller: sticks a label on the bottle;
- packer: puts the full bottles in the clean crates;

The brewery has two brewing and three bottling lines.

In the plant the production process can also be divided into three physical parts (figure 6):
- The brew house contains the malt, mash and wort processing.
- The cold room block contains the fermenting, conditioning and filtering sections. These rooms are all air cooled.
- The bottling halls contain the bottling process.

The brew house and the cold room block together form the main brewery building. The bottling halls are separate buildings (see appendix C1).

3.4.2 The utility system

The four primary energy carriers supplied to the brewery are fuel oil, electricity, water and air. Since most of the water at a brewery is heated sooner or later, the water system is treated as an energy subsystem. Air is free of costs, but the used quantity and its psychometric characteristics can influence the use of other energy carriers. The related conversion processes are the steam and condensate system, the electricity supply system and the water treatment and supply system.

Lower order conversion systems are the hot water system, the refrigeration system, the cold air system and the compressed air system.

- Steam and condensate system.

In a brewery the product has to be heated several times during brewing. Also hot water is needed for cleaning, washing, sterilizing and pasteurizing. The required heat is supplied by steam. A simple model is displayed in figure 7:

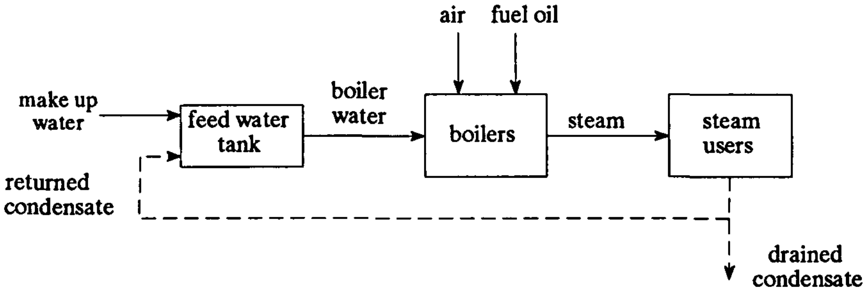


Fig. 7 The steam and condensate system

At TBL the system contains three boilers. One boiler is fully operating and one is stand by. The third has been installed at the end of '91 to support two new bottling lines. Unfortunately the tubes of this boiler burst in August 1993 because of overheating. The cause was scale forming because of insufficient water treatment. Up to now the boiler could not be repaired yet. The steam pressure of the boilers is 5.4 bar (80 PSIG). The used fuel is heavy fuel oil.

The steam is transported through pipelines to the users. The steam indirectly exchanges its heat with the users and condensate is created. A number of steam users return this hot condensate to the boiler, where it is again converted into steam. This is done to save heat as well as water. Other users drain the condensate.

Appendix C3 presents a more detailed drawing of the steam and condensate system with its users.

- Electricity system

Electricity (three phases) from the grid is transformed from 11 kV to 415 V. by means of two 1000 kVA and three 800 kVA transformers. (See figure 8). Appendix C4 presents the detailed electricity system.

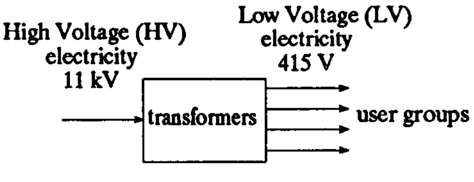


Fig. 8 The electricity system

- Water treatment and supply system

The water treatment and supply system is presented in figure 9. Water is supplied from the urban water works. Two water treatments are performed to give the water the required quality. Part of the water is only sand filtered. The rest is also passing a norit filter, which removes the chlorine, added by the urban water works.

Sand filtered and chlorinated (SC) water is used in

- the main brewery building for
  - cooling of the ammonia, air and CO_2 compressors;
  - brew house cleaning;
  - cleaning of fermenting, conditioning and filtering sections;

- the bottling hall for
  - crate and bottle washing;
  - pasteurizing;
  - cooling of the hydraulic system of the bottle fillers;
  - cleaning;

- head office and other offices for general purpose.

Sand filtered dechlorinated (SD) water is used in the main brewery building for:

- mashing and sparging processes in the brew house (brew water);
- flushing brew vessels and other vessels after cleaning with caustic;
- boiler make up water supply;
- drinking water;
- water supply for the condensers of the refrigeration plant.

Appendix C6 shows detailed drawings of the water treatment and supply system.

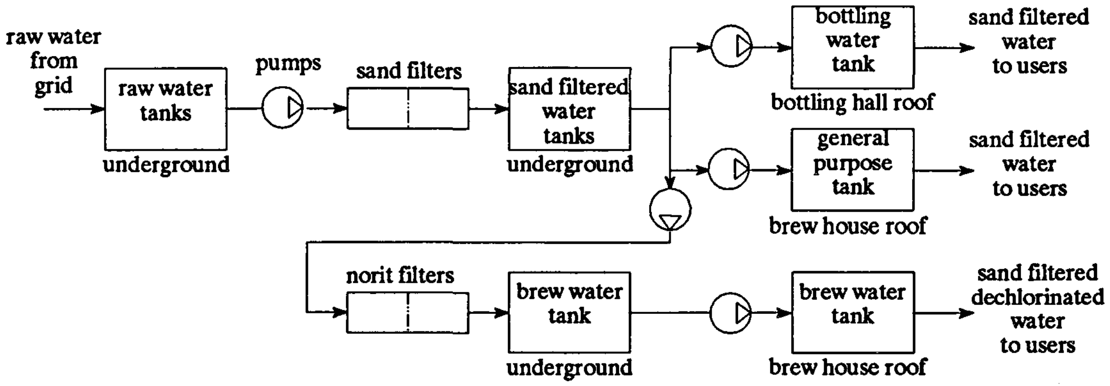


Fig. 9 The water treatment and supply system

- Refrigeration system

Electricity is mainly used for the refrigeration plant, to which much attention has been paid. A simple model of the refrigeration system is displayed in figure 10:

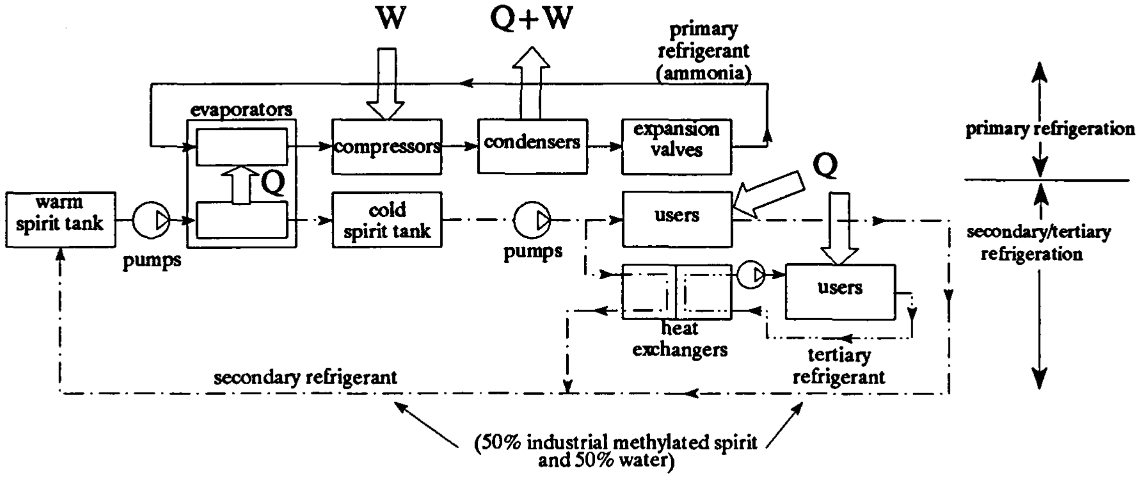


Fig. 10 The refrigeration system

The primary refrigeration system consists of seven separate cooling circuits, each consisting of a compressor, a condenser, an expansion valve and an evaporator. The used primary refrigerant in these circuits is ammonia. The evaporators exchange their cold with secondary refrigerant, which is a mixture of 50% water and 50% industrial methylated spirit (ethanol is the main ingredient). In this report secondary refrigerant is called spirit, like done at the brewery. This spirit is stored in two main tanks. From the cold spirit tank the spirit is pumped to the users. The returned warmer spirit is collected in the warm spirit tank. For some users a tertiary refrigerant is used. In the original plant design this was probably meant to use non poisonous refrigerant for those users where refrigerant is coming close to beer or a semi-product of beer. At present the tertiary refrigerant is also spirit, which is poisonous.

Appendix C5 shows detailed drawings of the refrigeration system.

- Cold air system

The cold air system can be seen as a user of the refrigeration system. Spirit is used to cool down air (figure 11). This air is used for keeping the cold room block at a constant low temperature. The air is not supplied from outside, but comes from the cooled spaces themselves (closed system). In total 16 air coolers are cooling 15 different spaces. The cooled spaces where beer is conditioning are called 'cold rooms'.

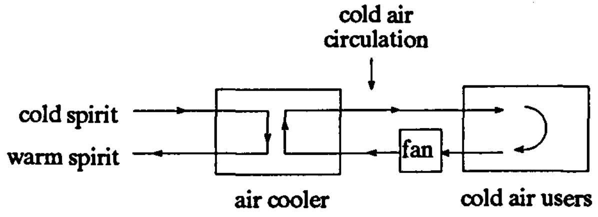


Fig. 11 The cold air system

- Compressed air system

Compressed air is obtained with the help of two piston air compressors (figure 12). After pressure in the pressure tanks has dropped below a certain value, the compressors refill the pressure tanks until the pressure in the tanks has reached a certain maximum pressure. Then the compressors are running unloaded. The pressure in the pressure tanks decreases because compressed air is flowing to the users. When pressure drops between a certain value, the same process starts again.

Compressed air is needed mainly for pressure during bottle filling. High air pressure is needed to reduce the forming of foam. Other users are the washers, pasteurizers and pneumaticly operated packers and unpackers of bottles into/out of crates.

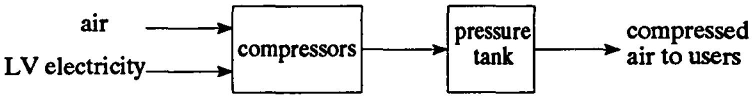


Fig. 12 The compressed air system

- Hot water system

Hot water is produced by heat exchange with steam as displayed in fig.13. Part of the supply water is hot water obtained by heat exchange during wort cooling (see energy recovery system below). The other part is cold water from the roof storage tank. One water tank is heated up to at least 50° C and another to at least 80° C. Hot water is needed during the mashing process as mash (50° C) and sparging water (80° C). Besides it is used for cleaning.

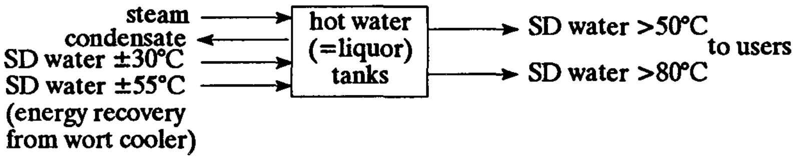


Fig. 13 The hot water system

3.4.3 The energy recovery system

Two ways of energy recovery can be recognized in the brewery: condensate return and wort cooling.

Condensate return has been explained in the paragraph about the steam and condensate system. Condensate has a temperature of 70 up to 100°C and contains more energy per litre than the colder boiler make up water. When this condensate is returned to and mixed with the boiler feed water, energy is saved.

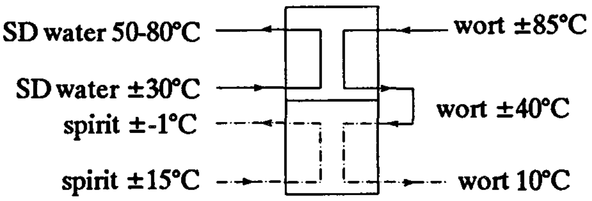


Fig. 14 Wort cooling with two step heat exchanger

As explained before, during wort processing hot wort is cooled down after hop separation. This is done with help of a two-step plate heat exchanger. (See figure 14). During the first step the wort is cooled down to about 40° C with water. In the second step the wort is cooled down further to 10°C by cold spirit. Only water cooling is a part of the energy recovery system and therefore the cooling with spirit is indicated with dashed lines in figure 14. The water used for cooling is brew water. After cooling wort, the water can have a temperature of 50°C up to 80°C and is transferred to the hot water system. Here it is used again as sparging water. In this way less steam is needed to heat up water for the hot water supply.

3.4.4 The total energy system.

In figure 15 all former aspects of the total energy system are integrated in one drawing. In the fermenting and filtering sections steam is used for cleaning and sterilization purposes.

For simplification some energy flows have been omitted in the drawing, but should be mentioned. Sand filtered chlorinated water is also used for cooling of CO_2, ammonia and air compressors. Also water with different kind of qualities is used for cleaning in every step of the production process.

Produced hot water can have a higher temperature then 50°C and 80°C respectively. To get the required 50°C and 80°C in the mash and wort processing the water is mixed with sand filtered dechlorinated water of 30°C.

3.4.5 Main problems of the brewery

To get an insight in the situation of TBL, some of their problems are discussed here. The joint venture with SAB is not an accidental occurrence, but a necessary step to cope with the problems.

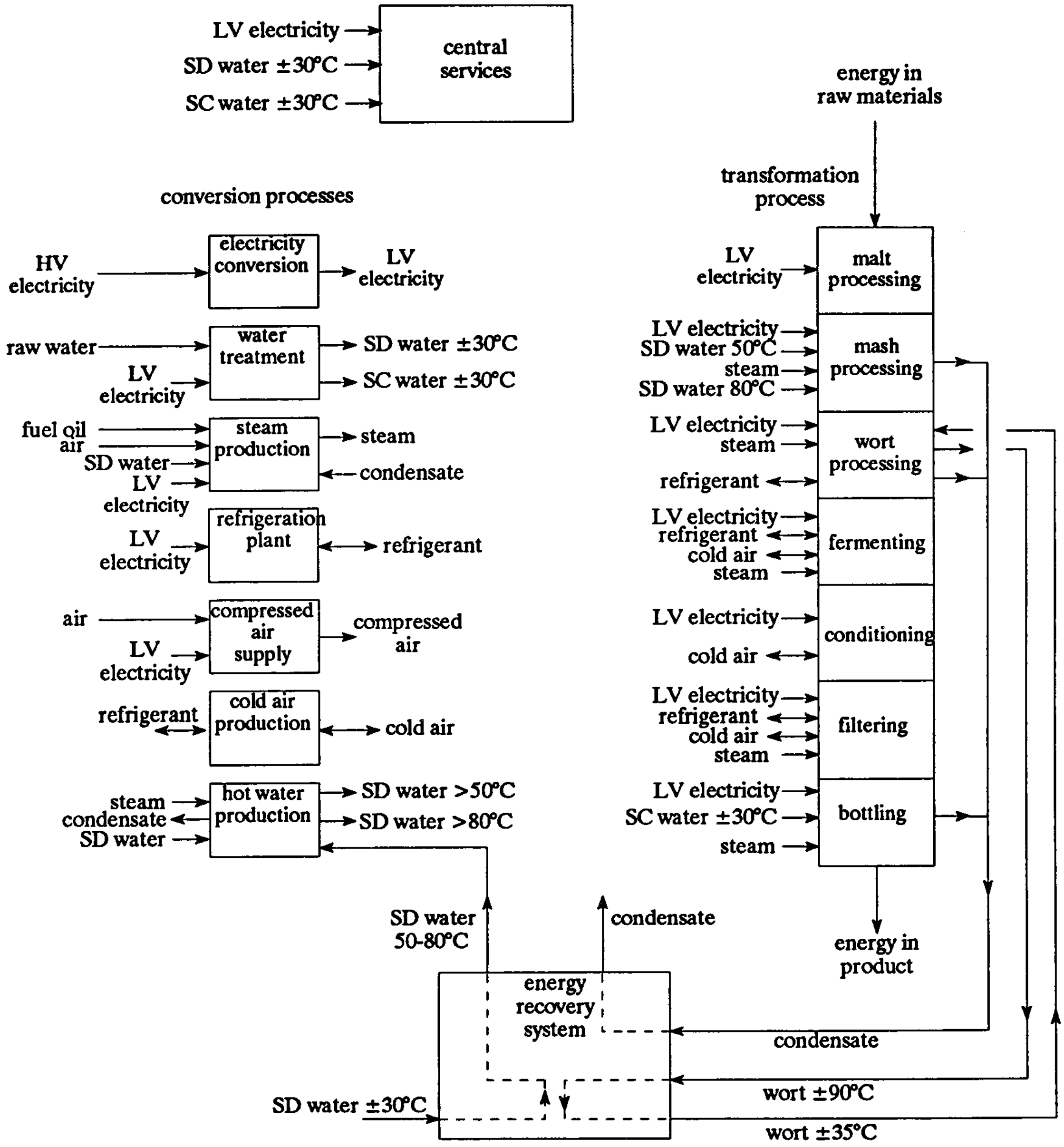
Productivity has been very low at TBL. In 1993 the Dar es Salaam plant produced about 300,000 hl with 950 employees. For comparison: at a certain Dutch brewery production is about 3,5 million hl with 650 employees. The production processes can be more or less fairly compared, because they are about the same.

The two newly installed bottling lines at the end of '91 didn't have the expected output. Though they were bought as new, it was suspected they were second hand. Many break downs occurred which delayed production. Besides, the lines consumed more water than the old lines used before. This came together with raw water supply shortages, resulting in more production stops. Also electricity power cuts decreased beer output.

Also the brewing section has its problems. The refrigeration system is not able to keep all users at the prescripted temperature. The main reason is old age and bad maintenance of the refrigeration system. Especially the compressors often revealed break downs.

Some problems are related to quality. A problem is the fact that a filled bottle of beer contains too much air. Therefore the tenability of the beer is not very long. A few months after production the beer is not drinkable any more. Usually pasteurized beer can be stored for at least half a year without substantial quality loss.

For the last years the company has had a continuous liquidity problem.



HV = High Voltage
LV = Low Voltage
SC = sand filtered chlorinated
SD = sand filtered dechlorinated
→| = ingoing flow
←| = outgoing flow
↔| = circulation

Fig. 15 The total energy system at TBL

4 Energy situation and related subjects

The evaluation of the energy situation and related subjects is mainly based on the model with direct and indirect factors influencing energy costs as indicated in section 2.4. For most indirect factors no thorough research was done to quantify the influence of these factors. Therefore their importance is assessed by naming some practical examples as experienced and observed at TBL. Because of the joint venture with SAB the situation is changing at TBL. Some factors influencing energy costs indirectly will be less or more important than before, e.g. the spare parts supply. The factors are mainly assessed on basis of the situation before the involvement of SAB for the following reasons:

- Since the involvement of SAB started only recently, the situation will be changing relatively fast in the coming two years. It is not very useful to describe and analyze the factors in this changing situation.
- This research is a part of a research programme, for which 'getting an insight in the industrialization process in Tanzania' is a main goal. In this frame work it is still useful to describe a situation which in fact is not there any more.

Not all factors in the model, mentioned in section 2.4, are treated here, because no information was available about these factors. The treated factors are energy prices and tariffs, applied technologies, production losses, capacity utilization, maintenance, beer consumption market, spare part supply, reliability of energy supply and utilities, quality and availability of raw materials, energy management, know how, investment possibilities and priorities, motivation, corruption and governmental influence.

4.1 Specific energy consumption

A global idea about the energy efficiency and possibilities of energy savings for the brewery can be obtained by looking at overall specific energy consumption and comparing the numbers with other breweries. By recording yearly consumption in 1992 and 1993 of fuel oil, electricity, water and the production output, the energy consumption per hectolitre (hl) beer output is obtained. This is the specific energy consumption. Here distinction is made between hectolitres of brewed beer, bottled beer and actually sold beer. Table 1 directly shows the big differences between specific energy consumption of brewed beer and sold beer, implying that much product is lost during the production process.

Table 1 Specific fuel oil, electricity and water consumption at TBL DSM
Data sources production numbers: [TBL3a: B3..I32]
energy consumption numbers: monthly engineering reports

Specific consumption		1992	1993
fuel oil	l/hl brewed beer	8.0	8.8
	l/hl bottled beer	10.5	9.4
	l/hl sold beer	11.0	10.1
electricity	kWh/hl brewed beer	23.1	27.4
	kWh/hl bottled beer	30.4	28.9
	kWh/hl sold beer	31.6	31.4
water	hl/hl brewed beer	34.9	44.8
	hl/hl bottled beer	46.1	47.4
	hl/hl sold beer	47.5	51.2

In table 2 also specific energy consumption is given for other breweries. As can be seen, TBL consumes much more energy then other breweries in the table. It should be taken in account that TBL is situated in a tropical country, so that more electricity has to be used for cooling purposes than in European breweries. On the other hand, the total time of cooling (fermentation and conditioning) per batch of beer is quite shorter than for most other beers. At TBL total cooling time is about 24 days, while for most western breweries cooling time is 4 up to 12 weeks. In section 5.6, page 73, an assessment is made about the influence of the climate on energy consumption.

The conclusion can be drawn that energy conservation is important and energy saving options seem to be present. TBL DSM consumes about 2 to 3 times more energy than a number of other breweries in the same range of production size.

Table 2 Specific energy consumption at TBL DSM in comparison with other breweries

Research or brewery	Beer output (hl/year)	Specific fuel oil consumption (l/hl beer)	Specific electricity consumption (kWh/hl beer)	Specific water consumption (hl/hl beer)	Specific energy consumption[5] (MJ/hl beer)
TBL DSM '93	300,000	10.1	31.4	51.2	579
Germany[1]	155,000	5.3	11.3	-	257
Germany[2]	100-500,000	3.2	10.3	6.5	168
Germany[3]	100-250,000	5.3	13.2	8.5	264
Ireland[4]	361,000	6.2	11.7	-	296
Turkey[4]	865,000	4.4	9.0	-	212

[1] Source: [Ehrh, p69,89]

[2] Source: Brauwelt nr. 9 (1992), p361, Betriebevergleich Energie 1990 by G.F. Schu

[3] Source: Brauwelt nr. 46 (1992), p2429, Richtzalhlen und ihr sinnvoller Einsatz in der Brauerei (II) by A.F. Mayer

[4] Source: [TIRDAF, p15]

[5] Includes specific fuel oil and electricity consumption

4.2 Energy costs

A way to assess the importance of controlling energy costs are the energy costs as a percentage of total costs. In table 3 can be seen that semifixed costs (electricity, fuel oil, water and refrigeration & steam costs) represent 21.6 % of total direct production costs. This number a substantial. In 1991 in the Netherlands the contribution of energy costs to direct production costs (excluding direct labour costs!) for breweries and malt houses was between 3 and 5% [CBS]. If energy costs at TBL could be reduced e.g. with 30% (including water costs), which seems very possible, direct production costs would drop 6%. The total contribution of semifixed costs to one crate of beer is 4.5% (table 4).

Table 3 Cost attribution of direct production costs per crate of beer
Data source: [TBL3a, B457..I483]

Cost attribution	TSh	%
Brewing materials	692	50.3
Bottling materials	269	19.6
Direct labour	36	2.6
Semifixed costs	297	21.6
Electricity	113	8.2
Fuel oil	103	7.5
Water	62	4.5
Steam/refrigeration	18	1.3
Repair & maintenance	82	6.0
	--------	--------
Total direct costs	1,377	100.0

Table 4 Attribution of gross sales per crate of beer
Data source: [TBL3a, B457..I483]

Attribution	TSh	%
Gross sales	6,595	100.0
Sales tax	3,241	49.1
Net sales revenue	3,354	50.9
Brewing materials	692	10.5
Bottling materials	269	4.1
Direct labour	36	0.5
Semifixed costs	297	4.5
Repair & maintenance	82	1.3
	--------	------
Total direct costs	1,377	20.9
Gross contribution	1,977	30.0
Marketing costs	386	5.6
Net contribution[1]	1,609	24.4

[1] Includes overheads, depreciation, interest on loans and profit

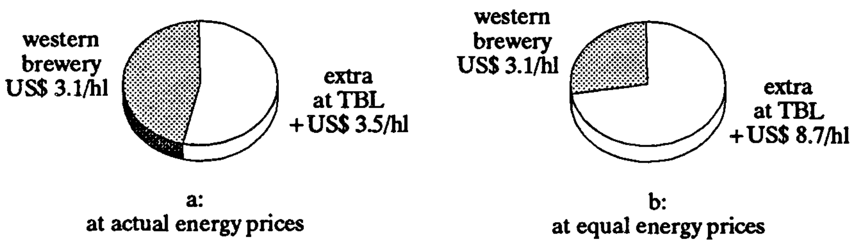
Another way of assessing the importance of energy cost reduction is the effect on the profitability of the company. For comparison with the results for total industry in Tanzania [Touss], the numbers have to be rearranged. Wanted are energy costs as a percentage of value added and gross profit. A problem at TBL for energy record evaluation is the fact that overheads are concentrated in the head office. A distribution of these costs over the various subsidiaries is difficult. Therefore the whole of TBL is considered in table 5. A net reduction of energy costs (fuel oil and electricity - investment costs) of 30% causes a gross profit increase of 43%. Cost reduction by energy conservation at TBL has a smaller effect on the gross profit than for the entire Tanzanian industry. The cause lies in the high sales taxes for beer (around 50% of sales price).

Table 5 Effect of cost reduction by energy conservation on value added and gross profit
Data source TBL: [TBL3a, various places]
industry Tanzania: [Touss, p18,19]

cost reduction by energy conservation [%]	increase of value added [%]		increase of gross profit [%]	
	TBL	industry Tanzania	TBL	industry Tanzania
10	2	4.5	14	97
20	4	9.0	29	192
30	6	13.4	43	288

Interesting is to make a comparison of specific energy costs with a western brewery. This reference brewery is based on the average specific energy consumption and costs for German breweries in 1991 with an annual production between 100-500.000 hl per year [Brauw, p2427-2429]. Specific energy costs for TBL are based on energy prices of 1/1/1994 to make a more actual profile. Specific energy consumption is based on 1993. Figure 16a shows that specific energy costs for TBL are more than twice as high in comparison with the reference brewery. Energy costs for the reference brewery are higher than for TBL. When both have the same energy prices, the specific energy costs for TBL would be almost four times as high as for the reference brewery (figure 16b).

The conclusion of this paragraph is that cost reduction by energy conservation is important from a financial point of view.



a:
at actual energy prices

b:
at equal energy prices

Fig. 16 Specific energy costs at TBL in comparison with a western brewery

4.3 Factors influencing energy costs

- **energy prices and tariffs**

A reference is made to report 1 of this research [Touss, p21]. One of the conclusion of this report is that, when devaluation is considered, electricity prices have been constant. Fuel oil prices have been fluctuating, but no increasing price trend (in US$) has been recognized. Table 6 gives water prices for industrial use for the last year in Tanzanian Shillings and United States Dollars according to the National Urban Water Authority (NUWA). Prices in US$ are decreasing.

Table 6 Industrial water price development in Tanzanian Shillings and United States dollars
Source: National Urban Water Authority, interview with quality manager

	1987	1988	1989	1990	1991	1992	1993
TSh/m^3	29.8	54.6	54.6	54.6	54.6	70.3	96.7
US$/$m^3$	0.43	0.50	0.35	0.28	0.24	0.23	0.24[1]

[1] exchange rate is assessed

According to government policy, since 1987 prices for electricity, fuel oil and water should be set in such a way, that the costs of their production can be recovered by sales (market oriented prices). Up to now this only succeeded for fuel oil (and other petroleum products). Water and electricity production still needs financial support from the government or third parties.

It can be concluded that for the application of energy conservation measures no extra reasons exist because of increasing energy price developments. Nevertheless the present costs for energy are high enough to consider energy costs reduction as a tool for cost reduction management.

The electricity tariff for the group to which TBL belongs is as follows (from 1/7/93):

a) Maximum Demand charge:	2,600 TSh per kVA of Billing Demand[1] (B.D.) per meter reading period[2]
b) Units charge:	
first 150 times B.D.(KVA) units	50 TSh/kWh
next 150 times B.D.(KVA) units	41 TSh/kWh
next 150 times B.D.(KVA) units	37.5 TSh/kWh
remainder of units	30 TSh/kWh
c) Costumer service charge per meter reading period.	40,000 TSh
d) Power factor surcharge if p.f.< 0.9	unknown

---

[1] Billing Demand is the higher of the KVA Maximum Demand during the month and 75% of the highest KVA Maximum Demand for the preceding 11 months

[2] Meter reading period: as near to 30 days as possible

The average power factor at TBL in 1993 was 0.83. This is lower than the indicated 0.9, below which surcharge has to be paid. However, TBL does not pay power factor surcharge for unknown reasons.

An example is given to explain the way how costs can be calculated with the tariff:

September 1993:	B.D.	1,960 kVA
	consumption	932,000 kW

Charge:

a)	1,960 * 2,600 =	5,096,000 TSh
b)	1,960 * 150 = 294,000 kWh * 50 =	14,700,000 TSh
	1,960 * 150 = 294,000 kWh * 41 =	12,054,000 TSh
	1,960 * 150 = 294,000 kWh * 37.5 =	11,025,000 TSh
	remainder = 50,000 kWh * 30 =	1,500,000 TSh
	total = 932,000 kWh	39,279,000 TSh
c)	surcharge	40,000 TSh
d)	power factor surcharge	0 TSh
a) + b) +c) + d) =		44,415,000 TSh

- **production losses**

Table 7 gives an indication of losses during the production process from the start of brewing up to actual sales.

Table 7 Production losses
Data source: [TBL3a, B3..I32]

	1992	1993
brew quantities after wort boiling (hl)	375078	315257
brewing losses (hl)	27180	20567
bottling losses (hl)	20385	10425
subtotal of losses (%)	13%	10%
stock losses (hl)	11079	22350
total losses (hl)	58644	53342
total losses (%)	16	17

The losses are 16% and 17% for 1992 and 1993 respectively and therefore very high. At a certain Dutch brewery total losses are 5 to 6%.

- **applied technologies**

The present brewery was built in 1966. Main expansions were in 1984 and 1991. About half of the equipment was installed in 1966. Of course wear and tear has had its influence on the quality and energy efficiency of this equipment.

The applied technologies are western ones. The only way to set up a large scale brewing production process is using these technologies. Due to insufficient maintenance these technologies are stripped from every frill. For instance automatic control systems were replaced by manual operation after break down. In the sixties used water in the bottling hall was recovered, but is now drained. The brewery expansion in 1991 was a turn-key project, which caused big starting up problems.

- **capacity utilization**

The production capacity after the capacity enlargement in 1991 at the TBL DSM plant is 7,741,440 cases of beer per year (968,000 hl/yr). The production volumes in 1992 and 1993 were 2,275,000 cases (284,000 hl/yr) and 2,383,000 cases (298,000 hl/yr) respectively, resulting in capacity utilizations of about 30%. This is very low. At a certain Dutch brewery capacity utilization is 80%. Causes can be found in table 8. This table describes down time in 1993 for the bottling lines. Total down time was 1858 hours. Gross operating time is 4160 hours per year. So the production could almost have been doubled if no down time would have occurred! It gives an indication of the importance of avoiding down time. Plant break down is by far the most important factor for down time. Improvement of the equipment, better spare part supply (logistics), faster repair and better preventive maintenance can be means to reduce plant break down. The influence of capacity utilization on the energy consumption will be evaluated in paragraph 5.1 on page 41.

Table 8 Average down time per bottling line in 1993 and causes
Source: TBL

Cause of down time '92		Average down time [hrs/bottling line]	%
External causes	No electricity supply	73	3.9
	Water shortage	173	9.3
Internal causes	No compressed air	164	8.8
	No steam	190	10.2
	Problems with beer filtering	281	15.1
	No empties	66	3.6
	Plant break downs	911	49.0
Total		1858	100.0

Table 8 only gives down time and causes for the bottling lines. Recorded down time of the brewing section is not available. The slowing down of the beer brewing process is partly caused by the same causes as for down time of the bottling lines: non-availability of electricity, water, steam and compressed air. Other causes are the not functioning of two out of three wort coolers. Also the non-availability of malt frequently occurred. This situation has improved after the interference of SAB.

- **maintenance**

The importance of maintenance can also be made clear by table 8. This table shows that about 70% (includes items 'no steam', 'compressed air' and 'plant break downs') of down time could be substantially reduced by improvement of maintenance.

Maintenance can be divided into two types [FacME, p1-6]:
- preventive: maintenance actions with the aim of preventing or delaying the failing of equipment. e.g. lubricating or replacing a still functioning component ;
- corrective: maintenance actions with the aim to repair defective equipment.

Preventive maintenance is performed in some cases for
- boilers;
- bottling lines;

- ammonia compressors;
- cleaning of brewing vessels, brewing areas and beer pipe lines. This type of maintenance is inevitable, because it prevents the production of smelly beer.

No maintenance is performed on steam, condensate and other pipe lines, insulation, water tanks, heat exchangers (except for the wort cooler plate heat exchanger) and civil works. Inadequate maintenance is performed for air compressors, air coolers and the total refrigeration plant. For maintenance of other equipment no data is known. For most equipment for which maintenance should be performed, instruction lists exist.

In most cases corrective maintenance is applied. When something brakes down, it will be repaired if spare parts are available. Equipment, not directly involved in beer brewing, is in most cases never cleaned. The maintenance system can be described as 'fire fighting'.

A first prerequisite for good maintenance is a full actual inventory of present equipment. It is known that for instance for electrical equipment an inventory is present, that, however, is not up to date and contains equipment already discarded.

- **beer market**

Though competition is increasing, until sofar TBL has been able to sell all of its products fairly easy. Most imported beers are at least twice as expensive as beer from TBL. An exception is beer imported from Kenya. This beer has been imported illegally on large scale and could be sold cheaply. No import tax was paid. In May '94 the government has taken action with effective result to stop this situation.

- **spare parts supply**

Most spare parts are imported from western countries. Some parts are made locally, like motor windings, pipe lines, water tanks and small simple metal parts. For these local made spare parts a stock does exist. With respect to most imported spare parts difficulties occur, because the foreign currency budget is very limited. Besides, corruption at the harbour often leads to delays. For instance in December '93 one of the capacitor banks for power factor correction burnt through. Though a new one is already in the DSM harbour, it wasn't at the brewery yet in May '94. Unknown is how the organization of spare part supply is set up.

- **reliability of energy supply and utilities**

Again a reference is made to table 8. The external supply of water and electricity caused 13% of down time, while internal supply of steam and compressed air accounted for another 19%. The delivery of fuel oil is reliable.

- **quality and availability of raw materials**

The most important raw material for beer is malt. Up to recently malt was partly imported and partly supplied by Moshi Maltings Ltd. The quality of locally produced malt was not very good and not constant. Not very good means that relatively much malt was needed to achieve the final alcohol percentage. Therefore also much sugar had to be added during wort boiling. A not constant quality resulted in process constants, like quantity of malt, amount of sparging water, boiling time, which were also subjected to changes. This influences energy consumption in a negative way. For instance wort boiling can take one up to three hours to get the required gravity (depends on the number of solids in the wort). As a result SAB decided to import all malts. At present only 2680 kg of malt is needed per brewing batch, while before 3900 kg was needed.

Beer bottles are locally made and have an insufficient quality. This results in many production losses at the bottling halls because of breaking bottles. This again can cause bottle shortage (see table 8).

- **energy management**

A problem is the lack of a system to control energy consumption. The registration of energy consumption for different kinds of equipment is poor. Only overall oil and electricity consumption are measured on a daily basis. For the steam and condensate system, the refrigeration system and the water system not enough measuring equipment is installed to be able to control energy flows. Energy flows to most of the equipment is controlled manually. To control those energy flows in an energy efficient way is difficult and requires motivated and skilled operators.

- **know how**

About know how on various areas not much is known. Known is that two engineers have had courses on the area of energy management, energy conservation and energy related cost benefit analysis.

- **investment possibilities and priorities.**

For energy conservation measures investments are needed. Capital has been mainly used for investments to expand the production process instead of improving it. A doubling of the design capacity at the end of 1991 did not lead to a doubling of production, but to a capacity utilization drop from about 50% to 32%. Also capital was used for improvement of welfare (housing for personnel, medical services). However, welfare expenses are only for staff employees. Management has had big problems to keep the plant running. So investments were also often used to remove present bottlenecks. Energy conservation investments have had a low priority. The Tanzania Industrial Research and Development Organisation (TIRDO) has performed energy audits in 1989 and 1991, which revealed profitable energy conservation opportunities. No measures were taken though.

However, management has been aware that energy cost should be reduced. A quotation of [TBL3]: 'Brewery operations must strive to reduce waste in water, steam, electricity, etc.'

It can be concluded that management is aware of high energy costs. Investment possibilities for energy conservation and maintenance were present, but were used for other purposes, probably partly because of pressure from the government.

- **motivation and corruption**

At TBL many employees are badly motivated. A main cause is the low wages. For most people, working for TBL, wages are too low to survive on only. In 1993 the wage for a work floor labourer was about 15,000 TSh (US$ 29) per month. Extra business has to be done to earn some extra money. This can be done during working hours in town or at TBL itself: chicken and fruit is for sale at TBL. Corrupt behaviour of one person can demotivate another. This can be explained by an example. A bonus system used to exist, in which mechanics received a bonus, when a maintenance job was done within a certain period of time. The person(s) who were in charge to select a mechanic for a certain job only chose their friends and split up the bonus. This situation of course demotivates other mechanics.

Corruption also has influence on know how. About ten years ago TBL was forced by the government to employ engineers, who were the first to enrol from the new technical faculty of DSM University. After ten years almost no engineer has been promoted to a responsible and leading function. Besides, engineers were blamed for mistakes they did'nt really make and were not listened to any more. The reason is probably that the present staff is afraid to loose their position and to be substituted by these engineers. Therefore a lot of know how is lost. More examples of corruption could be mentioned.

- **governmental influence**

For the past years TBL has been paying the normal 26.5% duties on imports. Some of their imports are duty free, like hops. During the refurbishment project by SAB, taking two years and starting from the beginning of '94, only 1,5% duties have to be paid on all imports. So this period is very suitable for importation of equipment, needed for energy conservation measures.

Some governernmental (energy) policies directly related to the subject are in the
Economic Recovery Programme (1986-1989):
- raising industrial capacity utilization from 20% to 60% at the end of the programme;

National Energy Policy (1992) [MWEM2]:
- to minimise energy price fluctuations in order to contribute to stability of prices in general through strengthening and rationalisation of energy supply sources and infrastructure and a rational energy prices structure;
- more efficient use of energy (in the transport) and industry sectors;

Short and medium term implementations of strategies, related to this report are [MWEM2, p15]:
- expansion and consolidation of the activities in energy auditing and in providing expert consultancy services to industry on industrial energy conservation;
- making industrial energy audits obligatory;
- the provision of duties and tax incentives with respect to equipment purchased for implementation of energy conservation measures;
- the consideration of making legal regulations to ensure implementation of recommended measures.

Up to now only the first two points of short and medium term implementations have been realized. In general it can be said that results from energy audits have been hardly implemented. It is believed that companies need more support on technological and financial areas to be able to implement results of energy audits.

- **level of the factors**

In figure 4 on page 18 the factors were distributed over various levels. Not enough research was performed to clearly point out on which level the main causes of high energy costs can be found. Some remarks can be made though.

The production process itself is of course the direct cause of the high energy costs. The level of management and engineering is an important level, because from there the initiative for improvement has to come. Factors on the level of 'external relations' have a varying effect. The beer market is large enough and energy prices are neither high (in comparison with western breweries) nor increasing. On spare part and raw material supply not enough research has been performed. The drop out of energy supply is an important factor and caused 13% of down time in 1993 and therefore contributes substantially to a lower capacity utilization.

4.4 Mass/energy balances

The base of an energy audit is the set up of an energy balance. Only when energy flows are known it is possible to assess the energy and cost savings by a certain energy conservation measure. Energy balances can also be used to estimate specific costs of higher order energy carriers. Energy and/or mass balances are set up for the major energy subsystems. These are the steam and condensate system, the hot water system, the electricity system, the refrigeration system and the cold air system and the water treatment and supply system. With help of these balances the energy flows, indicated in figure 15 page 28 can be quantified. Unfortunately far from all flows could be quantified. For the water treatment and supply system only water flows to the bottling hall could be assessed. For the compressed air system no balance could be made, because it was not possible to measure or assess the compressed air flows.

The calculations of the balances are worked out in appendix D1. This paragraph only gives main results and some comment. All balances are based on energy consumption and operating times in 1993. The balances are calculated for the whole year. Energy of water is defined as the heat needed to heat up the water from 0°C to the actual temperature. The energy content of raw materials are set on zero.

- **Steam and condensate system**

Overview steam and condensate system: appendix C3
Overview mass and energy balance of steam and condensate system: appendix D2a

For the set up of this balance no measuring possibilities were available to measure the separate steam flows to the users. Total steam consumption was assessed with help of the efficiency of the boilers and total fuel oil consumption. For the main users steam consumption was indirectly assessed by calculating the theoretical load or with help of steam consumption according to manuals. For a number of users steam consumption is unknown and can not be assessed. Only steam users in the bottling hall (pasteurizers and washers), the brewing vessels and hot water supply (hot liquor tanks) were involved in the calculation. Also condensate flows were quantified.

In 1993 2.8 million litres of fuel oil was needed to produce 24,200 MWh of steam. From this amount 8% was needed for hot water production (hot water system), 25% for mash heating, wort heating and wort boiling in the brew house and 40% was used for bottle washing and pasteurizing in the bottling hall. The not quantified users are assessed to contribute 28%.

About 57% of condensate is returned to the feed water tank of the boiler.

- **Hot water system**

Overview of the hot water system (as part of the total water system): appendix C6b
Overview mass and energy balance of hot water system: appendix D2b

Partly hot water is obtained by heat exchange with steam. About 8% of total steam production is needed for this process, as mentioned in the previous paragraph. For another part hot water is obtained by heat exchange of cold water with hot wort (heat recovery) during the wort cooling process. The energy needed for the production of hot water consists for 63% of steam and for 37% of heat recovered from wort. This situation is certainly suitable for improvement, because about 40% of the hot water, obtained by heat exchange with wort, is drained.

- **Electricity system**

Overview electricity system: appendix C4
Overview energy balance of the electricity system: appendix D2c

In 1993 8,600 MWh has been consumed in total.

With respect to the users it was only possible to measure electricity consumption for the ammonia compressors in the refrigeration plant, the water pump house and the air compressors. The rest was assessed with help of a total list of equipment with their rated power consumption and a record of currents for the different user groups.

The refrigeration plant accounts for around 66% of the electricity consumption and is by far the biggest consumer.

- **The refrigeration and cold air system**

Overview refrigeration system and cold air system: appendix C5 a and b
Overview energy balance of the electricity system: appendix D2d and e

Electricity consumption of the refrigeration system not only includes electricity consumption for primary refrigeration to obtain cold secondary refrigerant (spirit). Also a substantial amount is needed for pumping secondary and tertiary spirit to the users. The ammonia compressors consume about 63% of the electricity, consumed by the total refrigeration system. The remainder is consumed by water and spirit pumps and air cooler fans.

Air cooling is the biggest refrigeration load and accounts for 72% of the total refrigeration load.

4.5 Specific energy costs per carrier

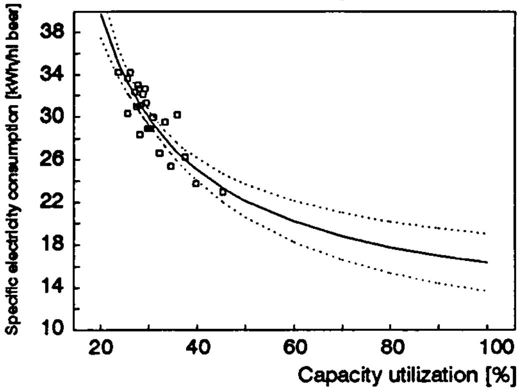
With help of the balances set up in appendix D2 prices of lower order energy carriers, like spirit, cold air and steam flows can be calculated. Appendix E gives an overview of prices and calculations.

5 Evaluation of energy conservation opportunities

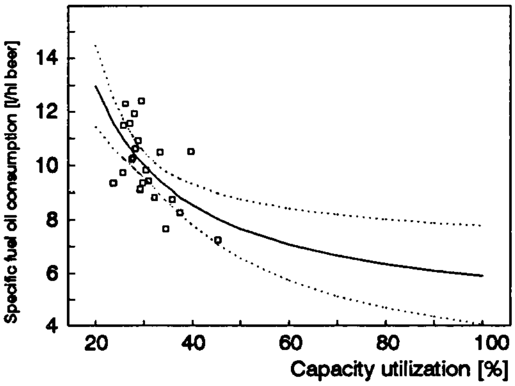
5.1 Improvement of capacity utilization

- <u>ECO: improvement of capacity utilization in order to reduce specific energy consumption</u>

a: Electricity



b: Fuel oil



c: Water

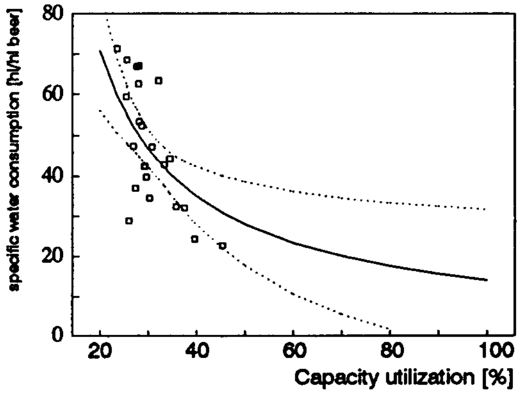


Fig. 17 Specific electricity, fuel oil and water consumption per month as a function of capacity utilization (based on 1992 and 1993)

- cost benefit analysis

By making graphs of specific energy consumption per month plotted against capacity utilization in this month, some assessments can be made about the influence of capacity utilization on the specific energy consumption. See figure 17a, b and c. The full lines are a model based on the samples (squares). First a relation was computed by linear regression between production and energy consumption. This model was converted to a relation between specific energy consumption and capacity utilization. The linear regression was based on data pairs of the production of a specific month and the average energy consumption of the same and previous month. The reason is the fact that the production time cycle of beer is about one month, so that energy needed for the production in a certain month also was consumed in the previous month. This effect is most clear for fuel oil consumption. Fuel oil (or steam) is mainly needed during wort processing and bottling, or in other words, during the beginning and the end of the production time cycle. The dotted lines are the spread (2σ) between which the mean specific fuel oil, electricity or water consumption per month will fall for a certain capacity utilization. For higher capacity utilizations these borders diverge much.

For water no average of actual and previous month has been used, because monthly water consumption was recorded from the fifteenth up to the fifteenth of the month. The relation found between water consumption and production gave a trend of decreasing water consumption during increasing production. This seems impossible. Therefore the graph for water in figure 17 is based on constant average water consumption regardless production volume. The applied method and an example calculation are elaborated in appendix F1.

In Figure 18 the expected and minimum energy cost savings per unit of output for higher capacity utilizations are given. The figure is based on the same model as used for figure 17. The left figure gives energy cost reduction based on the full lines in figure 17 and the right figure uses the upper dotted lines. A capacity utilization increase from 30% percent to 60% (100% production increase) results in an estimated 36% decrease in energy costs per case of beer. Minimal expected decrease of specific costs is 22%. Of course the feasibility depends on the costs which accompany the increase of capacity utilization. These costs are difficult to quantify.

The reduction of specific energy costs is not the only reason to improve capacity utilization. Other specific costs for investments, labour and administration will also decrease.

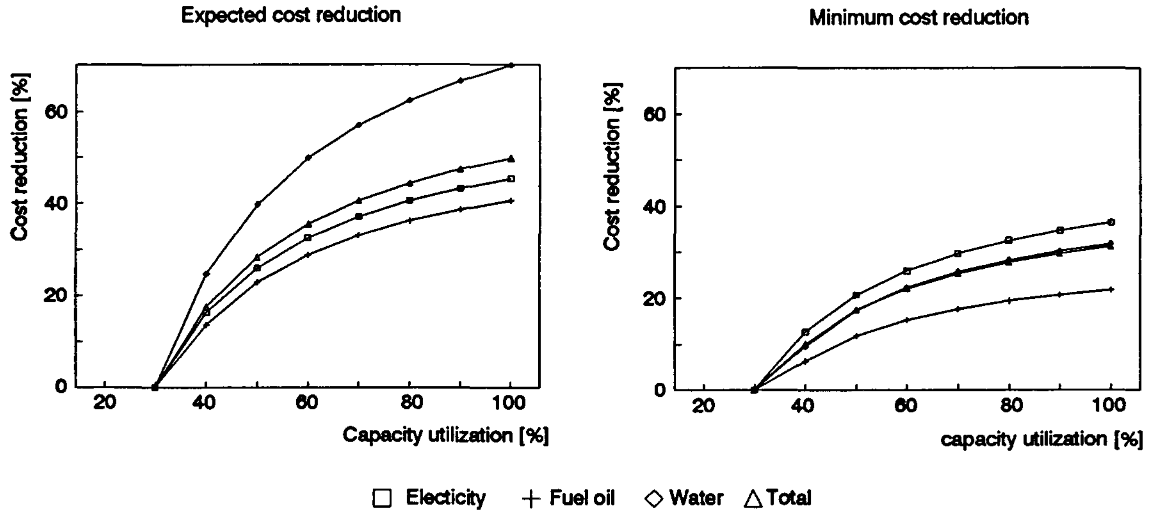


Fig. 18 Reduction of specific electricity, fuel and water costs as a function of capacity utilization
Left: expected cost reduction; right: minimum cost reduction

5.2 Reduction of production losses

- ECO: reduction of production losses in order to reduce specific energy consumption
- cost benefit analysis

Table 7 in section 4.3, page 34, showed that total losses from brewing to selling were 17% in 1993. Figure 19 shows how specific energy costs decrease when losses decrease. An assumption is that the percentage of reduction of specific energy consumption causes a same percentage of energy cost reduction. It is also assumed that in average all losses occur when 70% of the energy, consumed for producing one hectolitre of bottled beer, is used to produce those losses. This percentage is based on the fact that

- most brew losses occur after or during the fermenting process, when already about 70% of the energy for the brew section is consumed (See appendix D2g);
- most bottling losses occur after bottle filling, when already 70% of the energy for the bottling section is consumed.

To calculate the new specific energy consumption (energy consumption per hl of bottled beer) for a production with less losses the following formula is used:

$$\textit{new sp. energy consumption} = \frac{\textit{old energy consumption} + \textit{extra energy consumption new production}}{\textit{new production}}$$

Calculations are based on energy prices of 1/1/1994. An example calculation is given in appendix F2. When losses can be reduced to e.g. 8% (about half of the losses in 1993), the specific costs will reduce 8% in 1993. This is a substantial improvement. The costs for implementation of a decrease of losses are unknown.

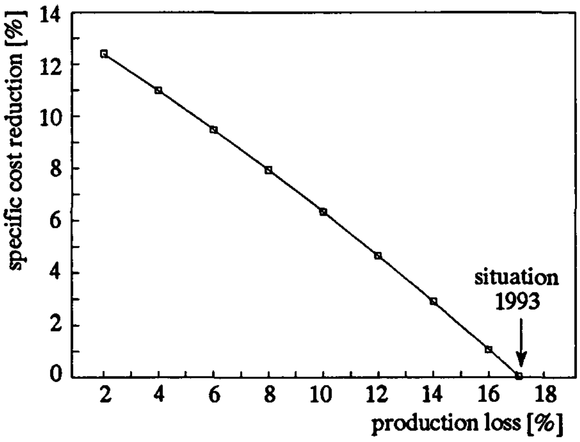


Fig. 19 Specific energy cost reduction as a function of production loss

5.3 Improvement of energy efficiency by technology, maintenance and organisation improvement

5.3.1 Improvement of the steam and condensate system

Boilers

- ECO: installing energy recording equipment

No adequate equipment is installed to determine energy flows. Fuel oil consumption is measured by dip-stick in the fuel oil tanks. Steam and/or feed water flows are unknown. In this way it is difficult to perform an energy audit. Besides, it is also important that the boiler maintenance people can detect sudden or slowly changes in steam consumption and act correspondingly (feed back).

- ECO: improvement of maintenance and housekeeping measures

In principle a good maintenance program exists for the boilers. It includes a two weekly cleaning of the burners and a half yearly inspection of the tubes for scaling and leakages. But short comings are:
- Fuel oil which flows to the boiler is preheated by steam. The pipe line from the service fuel oil tanks, where the oil is preheated, to the boilers is uninsulated.
- The area looks very oily. The cause can be fuel oil pipe leaks or an overflow of the oil service tanks.
- Feedwater pumps are leaking.
- The blown down outlet blows hot water and steam in the open air near the boiler house, very close to the place where people are collecting spent grains. This is a dangerous situation.

- evaluation

The necessary measures are:
- repair of the water pumps;
- cleaning of area polluted by oil and measures to prevent oil spoilage in the future;
- repair of the blow down outlet.

The feasibility of insulation of the fuel oil pipe line will be treated later in this paragraph ('steam distribution', page 46).

- ECO: improvement of boiler performances

In appendix D1 the efficiency of the boilers was assessed to be 70%. The efficiency of a boiler depends on the quantity of flue gas losses, radiation losses, blow down losses and load losses. The separate losses are assessed to be (Appendix D1, section 1):

Flue gas loss	14%
Radiation loss	4%
Blow down loss	1.5%
Load loss	10%

- theory

The quantity of flue gas losses is first of all determined by the amount of air in the incoming fuel oil/air mixture. In theory the required amount of air equals the required air to combust all injected fuel oil. In practice a certain percentage of excess air is required to get a complete combustion. When the excess percentage is too high, efficiency will decrease, because additional energy is required to heat up the excess air. When the excess percentage is too low, efficiency will also decrease, because not all fuel oil will be completely combusted. At a certain percentage of excess air is the optimum.

The second decisive factor of flue gas losses is the heat exchange between combustion gasses and water (steam to be) in the boiler. When heat exchange is bad, e.g. because of polluted or scaled heat exchange surfaces, the flue gas temperature will increase, resulting in higher flue gas losses.

Symptoms of too much excess are:
- a too high percentage of oxygen in the flue gas;
- a too low percentage of CO_2 in the flue gas;
- a too low temperature of the flue gas.

Symptoms of too little excess air are the opposites of above and black smoke from the stack as a sign of bad combustion. The symptom of insufficient heat exchange between combustion gasses and water is a too high temperature of the flue gas.

- measurements

All above mentioned parameters were measured. The colour of smoke from the stack is measured with a smoke indicator. A higher smoke number means more soot in the flue gas.
The measurements gave the following results. The ideal manual values are also given:

measurement	Boiler 1 test	Boiler 2 test	Manual
vol % O_2 flue gas	7.6	-	5.2
vol % CO_2 flue gas	10.4	11.0	12-14
flue gas temp. [°C]	182	175	unknown
ambient temp. [°C]	34	34	
smoke indicator	2	3	<4
flue gas losses [%]	14-15	13-14	12
excess air [%]	50	43	20

With help of the graph in appendix D3b (relation excess O_2, CO_2, air and loss percentage) and the above data the percentage of excess air can be determined. The following conclusions can be drawn:
- The smoke indication is within the limit, so excess air is enough for complete combustion.
- The percentage of oxygen in the flue gas is too high, resulting in an excess air percentage of 50% and 43% respectively, while the desired value is 20%.
- Unfortunately the desired stack temperature is not known. However, flue gas temperature is not high in comparison with the temperature of the water in the boiler (6.4 bar abs., 160°C). Therefore it is assumed that heat exchange of combustion gasses with water is sufficient.

The percentage of excess air is too high. A reduction of this parameter to the prescribed 20% may increase efficiency with about 1½%. (see appendix D3b). When control of the percentage of excess air is applied, a flue gas analyzer has to be purchased.

- cost benefit analysis

Energy cost savings:
42,000 * 91 = 3.8 million TSh/yr = US$ 7,500/yr with
42,000 = 1½% of total fuel oil consumption per year [l];
91 = fuel oil price: [TSh/l].

Investments: costs of flue gas analyzer: US$ 500 (source:[TIRDAF, p39]).
Foreign currency component: 100%.

Pay back period: less than one month.

Though this measure is very profitable, some draw-backs have to be mentioned. Personnel should be instructed very well, because too little excess air causes sooted tubes, so that the measure will have an opposite effect. The yearly savings are only small. Therefore a careful consideration has to be made by the management before applying this energy conservation option.

For other boiler losses no energy conservation opportunities were found.

Steam distribution

- ECO: insulation of steam pipe lines

- cost benefit analysis

Table 9 gives an overview of the feasibility of the (re)insulation of steam pipe lines. For the insulation glass wool was chosen with an aluminium cover. The lifetime of insulation is about five years. This means that insulation of steam pipe lines is feasible. Another reason for insulating steam pipe lines is the safety of the personnel.

Table 9 Feasibility of insulation of steam pipe lines

Steam pipe to	dimension [inch]	length [m]	surface temp [°C]	specific heat loss [W/m]	operating time [hrs/yr]	energy savings [MWh/yr]	energy savings ['000 TSh]	insulation costs ['000 TSh]	Pay back period [years]
fuel oil preheater	1	15	130	100	5,460	7	88	105	1.2
CO2 plant	1	50	130	100	5,460	25	295	350	1.2
filter room (sterilization)	2	50	130	250	5,460	61	737	700	0.9
old brew house (main pipe)	6	5	80	250	5,460	6	74	210	2.8
old wort kettle (from main pipe)	3	12	80	100	5,460	6	71	250	3.6
old mash vessel (from main pipe)	3	10	80	100	5,460	5	59	210	3.6
hot water tanks (from main pipe)	2	5	90	50	5,460	1	15	70	4.7
old bottling hall	4	70	80	200	4,160	52	629	1,960	3.1
water pump house	1	20	130	200	5,460	20	236	140	0.6
total						183	2,200	4,000	1.8

Remarks:

- the foreign currency component of the insulation costs is 100%;
- calculations are based on an outside ambient temperature of 26°C and an inside ambient temperature of 30°C;
- specific heat loss is obtained with help of the table in appendix D3f (bare surface losses), the surface temperature and pipe size (dimension);
- it is assumed that 90% of the bare pipe losses are saved by insulating;
- yearly savings [MWh] are calculated by multiplying specific heat loss, pipe length and operating hours and taking 90% of that value;
- yearly savings [TSh] are obtained by multiplying yearly savings [MWh] with steam costs per MWh (appendix E)
- insulation costs are based on pipe lengths and prices of insulation with aluminium cover as indicated in appendix E.

- ECO: repair of steam leaks

Steam leaks were noticed in:
- pipe line to the hot water tanks combined;
- pipe line to hot water tank 1 (very near tank);
- pipe line to fermentation rooms on the roof;
- pipe line in the filter room;
- pipe line in the old brew house going up to higher floors (near malt silo's);
- pipe lines and flanges in the water pump house.

- cost benefit analysis

Steam losses from leaks can be determined with help of appendix D3e. For the existing steam system at TBL this is about 3 kg per hour per mm^2 hole. A one mm^2 hole causes an energy loss of 10 MWh per year, which costs 120,000 TSh/mm^2 = US$ 240/mm^2 .

Repairing steam leaks is not very expensive, so that this repair is quite profitable. Nevertheless, real big costs savings can not be achieved. Anyway, not repaired steam leaks will become bigger and are a danger for the personnel. Irrespective of financial benefits, steam leaks should be repaired.

- ECO: repair of cut-off valves

A general complaint of the personnel is the malfunctioning of steam cut-off valves. This accounts for cut-off valves for separate consumers as well as main cut-off valves for a certain group. When only the brew house is operating, also steam is seeping through to the bottling hall. The costs of these losses are difficult to estimate, but bad valves should be replaced on instruction of the personnel.

- ECO: repair of steam traps

Steam traps have been tested with an ultrasonic steam trap tester. All steam traps proved to be in a good condition except for the ones used at the new mash and wort vessel. Loud continuous noises were recorded in the traps. Also condensate temperatures were higher than measured anywhere else, which can mean that steam is seeping through. The higher temperatures may also be caused by higher condensate pressures, because the pipe lines are first going up before returning to the boiler feed water tank. When the refurbishment of TBL starts, these traps should be checked first by experts.

Condensate return

- ECO: insulation of condensate pipe lines

- cost benefit analysis

Table 10 shows the feasibility of bad or not insulated condensate pipe lines. The chosen insulation material is again glass wool with aluminium cover. Also this measure is feasible.

Table 10 Feasibility of insulation of condensate pipe lines

Condensate pipe line	dimension [inch]	length [m]	surface temp [°C]	specific heat loss [W/m]	operating time [hrs/yr]	energy savings [MWh/yr]	energy savings ['000 TSh]	insulation costs ['000 TSh]	pay back period [years]
from new bottling hall (in old bottling hall)	3	50	80	170	4,160	32	541	1,050	1.9
from old bottle washer	3	14	90	200	2,000	5	86	295	3.4
combined pipes from bottling halls to ogden pump	3	15	80	210	4,160	12	200	315	1.6
from ogden pump bottling hall to feedwater tank	2	130	90	120	4,160	58	993	1,820	1.8
from hot water tank 1 to feed water tank	2	30	90	100	2,000	5	92	420	4.6
from hot water tank 2 to feed water tank	2	50	70	90	2,000	8	138	500	3.6
from old brew line to ogden pumps	3	40	70	120	5,460	24	401	680	1.7
from ogden pumps old brew line to feed water tank	3	20	90	160	5,460	16	267	340	1.3
total						160	2,720	5,420	2.0

Remarks: see table 9

- ECO: increase of condensate return

When steam has exchanged heat with its user, condensate remains. Returning this condensate to the boiler feed water tank will save energy, because the energy content of condensate is higher than the boiler make up water. In this way also less make up water is needed.

At present most of the quantified steam consumers return condensate (see appendix C3). For most of the steam consumers, which don't return condensate, the condensate flows are unknown, so that cost benefit analysis is impossible. However, out of the quantified steam consumers, also the old pasteurizer and the old mash vessel don't return condensate. Condensate return from the old pasteurizer is out of the question, because steam is directly injected. For the old mash vessel a cost benefit analysis can be set up to check the profitability of condensate return.

- Cost benefit analysis: condensate return from old mash vessel

Savings per year:
The costs of condensate are the costs of steam, needed to heat up the condensate from cold prepared water temperature (30°C) to the actual temperature (100°C). Also the costs of water have to be added. So the savings when condensate is returned are:
energy: 724 * 4.2 * (100-30) / 3,600 * 12,000 with
724 = quantity of condensate [tonnes/yr];
4.20 = specific heat of condensate [kJ/kg];
(100 - 30) = temperature difference [°C];
3,600: = conversion factor MJ to MWh;
12,000: = costs of steam [TSh/MWh];

water: 724,000 * 173 = 125,000 TSh with
724,000 = quantity of condensate [kg/yr];
173 = costs of treated water [TSh/tonne].

Energy savings	710,000 TSh
Water savings	125,000 TSh
Total savings	835,000 TSh

Installation costs:	
6 m 2½" pipe line	45,000 TSh
6 m insulation (glass wool)	156,000 TSh
other costs (10%)	20,000 TSh
Total costs	221,000 TSh
Foreign currency component:	70%.

Payback period with insulation: 3 months.
Payback period without insulation: 1 month.

This measure is very feasible. Annual savings will be at least 614,000 TSh (= US$ 1200) with insulation and 770,000 TSh (= US$ 1500) without insulation per year. Though very feasible, this opportunity does not save a very big amount of money.

- ECO: insulation of boiler feedwater tank

See insulation of process vessels.

Steam consumers

- ECO: insulation of process vessels

- cost benefit analysis

The insulation of the process vessels with glass wool is feasible, when the assumed lifetime is five years. Some vessels may be difficult to insulate. Considering this fact and the rather long pay back period, it may be better not to implement this measure.

Table 11 Feasibility of insulations of vessels and tanks

process vessels	area [m²]	surface temp [°C]	specific heat loss [W/m²]	operating time [hrs/yr]	energy savings [MWh/yr]	energy savings ['000 TSh]	insulation costs ['000 TSh]	Pay back period [years]
old mash vessel	40	65	500	2,900	52	887	3,200	3.6
old lauter tun	33	75	600	1,800	32	545	2,640	4.8
old wort kettle	55	95	900	2,300	102	1,742	4,400	2.5
whirlpools	42	90	800	1,500	45	771	3,360	4.4
boiler feed water tank	40	53	400	8,760	126	2,144	3,200	1.5
total					357	6,090	16,800	2.8

Remarks (table 11 continued):

- the foreign currency component of insulation costs is 100%;
- specific heat loss is obtained with help of the table in appendix D3f (bare surface losses) and the surface temperature;
- operating hours for the brew house vessels are an average of around 10 aselect brew batches, multiplied by the number of batches per year;
- it is assumed that 90% of the bare surface losses are saved by insulating;
- yearly savings [MWh] are calculated by multiplying specific heat loss, surface area and operating hours and taking 90% of that value;
- yearly savings [TSh] are obtained by multiplying yearly savings [Tsh] with steam load costs per MWh (appendix E);
- insulation costs are based on surface areas and the price of insulation (glass wool) with aluminium cover as indicated in appendix E.

5.3.2 Improvement of the hot water system

One way to improve the hot water system is improvement of water recovery from the wort heat exchanger. This will be dealt with in paragraph 5.3.4, page 55, 'improvement of the refrigeration system', because this ECO also involves refrigeration.

Another ECO is insulation of hot water pipe lines and tanks

- ECO: insulation of hot water pipe lines and tanks

- cost benefit analysis

Because water pipe lines and tanks have lower surface temperatures, they can be insulated with styropor. The results are displayed in table 12. Insulating water pipe lines and tanks is very feasible.

Table 12 Feasibility of insulation of hot water pipe lines

water tank	area [m^2]	surface temp [°C]	specific heat loss [W/m^2]	operating time [hrs/yr]	energy savings [MWh/yr]	energy savings ['000 TSh]	insulation costs ['000 TSh]	pay back period [years]
paraflow tanks (2x)	120	58	400	8,760	378	6,430	580	0.1
hot water tank 1	74	76	600	8,760	350	5,950	360	0.1
hot water tank 2	44	64	250	8,760	387	1,470	210	0.1

water pipe line	dimension [inch]	length [m]	surface temp [°C]	specific heat loss [W/m]	operating time [hrs/yr]	energy savings [MWh/yr]	energy savings ['000 TSh]	insulation costs ['000 TSh]	pay back period [years]
from wort cooler to paraflow tanks	3	110	60	130	2,400	31	525	280	0.5
from paraflow tanks to hot water tank 1	2½	130	55	80	2,400	22	382	280	0.7
total						868	14,800	1,700	0.1

5.3.3 Improvement of the electricity system

Measurements on the transformers were done to obtain their load and power factors. The results are in table 13.

The following remarks can be made about the results:
- The load factors are very low.
- The power factors of most transformers are low and are compensated by transformer 1, which has a capacitive load. Probably the capacitor bank of transformer 1 is manually switched on maximum capacity.
- The total apparent power consumption is 1700 kVA, while the maximum recorded power consumption in 1993 (Billing Demand, see paragraph 4.3, page 33) was 2,100 kVA.

Table 13 Measurements and elaborations of the transformers

Transformer number	Rated apparent power [kVA]	secondary measurements			Consumed apparent power [kVA][2]	kVA Load factor [-][3]
		line current [A]	line voltage [V]	power factor [-]		
1	1,000	500[1]	400	- 0.64[1]	346	0.35
2	1,000	1,000[1]	400	0.83[1]	693	0.69
3	800	556	400	0.81	385	0.48
4	800	215	400	0.73	149	0.19
5	800	380	400	0.68	124	0.16
total/average					1,697	0.31

[1] These values are read from meters, because measurements were not possible (cables out of reach)

[2] Consumed apparent power = line voltage * line current * $\sqrt{3}$ /1,000 [kVA]

[3] kVA load factor = consumed apparent power / rated apparent power

- ECO: improvement of kVA load factor

The overall load factor proved to be 0.31. This is low and results in lower efficiency. For instance losses by eddy currents are more or less constant and efficiency drops with a lower load factor. The graphs in [Stig, p114,115] show that the total loss percentage increase with about 2%, when the load factor is 0.3 in stead of 1.0. Appendix C4 shows that the loads of transformers 1,2 and 3 can be interconnected by busbar switches. The same accounts for the loads of transformers 4 and 5. However, the loads of transformers 1, 2 and 3 can not be interconnected with the loads of transformers 4 and 5. An underground cable with a new busbar switch should be installed to make this possible. The best solution would be that the total electrical load is connected to transformers 4, 5 and 6. These transformers probably have a higher efficiency, because they were manufactured in 1991, while transformers 1 and 2 were installed in 1969. Transformers 1 and 2 can be switched off in this new situation. The total rated power of transformers 4, 5 and 6 is 2,400 kVA, resulting in a load factor of 0.7 under previous measurement conditions and in a load factor of 0.88 during maximum power consumption in 1993. The electricity savings will be at least 2 % of total electricity consumption in 1993.

- cost benefit analysis

Savings: 172,000 * 52 = 8.9 million TSh/yr = US$ 17,500 with
172,000 = 2% of total electricity consumption in 1993 (8,600 MWh) [kWh];
52 = average electricity price [TSh/kWh].

Assessed costs for underground cable and busbar switch: 3 million TSh = 6,000 US$.
Foreign currency component: 100%.

Pay back period: 4 months.

- ECO: reduction of peak consumption by peak demand management

By levelling the electricity demand, peak demands will be lower, resulting in lower electricity bills. See paragraph 4.3, page 33 for the electricity tariff system.

- cost benefit analysis

An analysis of an arbitrary month is made to check the importance of reducing peak consumption:
Peak demand: 2,100 kVA;
Electricity KVAh consumption Nov. '93: 939,400 kVAh;
Operating hours refrigeration (66% of demand): 360 * 24 = 8,640 hrs/yr;
Operating hours rest (34% of demand): 260 * 18 = 4,680 hrs/yr;
Average monthly operating hours: 608 hrs/mth;
Average demand: 939,400/608 = 1,545 kVA.

This calculation was also done for other months in 1993:

	Peak demand [kVA]	Average demand [kVA]
Jan	1,640	1,257
Apr	1,820	1,359
May	1,840	1,499
June	1,620	1,214
July	1,640	1,280
Sept	1,960	1,512
Nov	2,100	1,545
Dec	2,100	1,787

This data agrees with the measurements in table 13. On average demand per month is about 78% of peak demand per month. In principle peak demand management is possible. However, few electric loads are suitable for demand management. Loads of the refrigeration plant, pump house, air compressors and boilers (78% of total power consumption) can not be switched off when needed for demand management. Batch processes are more suitable for application of peak demand management. The only batch process in a brewery is in the brew house, which consumes a little quantity of electricity.

It can be concluded that the reduction of peak consumption by peak demand management is not very useful at TBL. Nevertheless, peak consumption can be reduced by an improvement of the power factor and by energy consumption reduction of the electrical load.

- ECO: improvement of the power factor

When the power factor is improved, electrical consumption costs will reduce. In paragraph 4.3 it was stated that TANESCO punishes a power factor which is lower than 0.9, but in reality TBL does not pay this penalty. However, a higher power factor will lead anyway to lower electricity costs because of the present tariff structure. The peak kVA demand will be lower and the costs are based on this peak demand.

- cost benefit analysis

The average power factor in 1993 was 0.83. This could be increased to 0.95 by improved power factor correction. For instance for August 1993 the consumption data were:

peak demand (M.D.): 2,100 kVA ;
consumption: 779,700 kWh;
Costs: 38.7 million TSh;
Power factor: 0.83.

Assuming that the consumption (in kWh) does not change, the peak demand in case of a power factor of 0.95 is 0.83 / 0.95 * 2,100 = 1,835 kVA. According to the present tariff system the costs will be 33.8 million TSh. So an improvement of the power factor with 14% will reduce costs with 5%. This means that the present tariff is quite sensitive with respect to peak demand and therefore the power factor.

Based on the electricity consumption in 1993, a cost reduction of 5% and the present tariff structure, the annual savings will be 21.4 million TSh = US$ 42,000. Costs for repairing or installing new power factor correction equipment is unknown. SAB has included a power factor improvement in the refurbishment.

5.3.4 Improvement of the refrigeration system

Ammonia system (primary refrigeration)

- findings

Measurements and observation gave the following findings:

- many ammonia compressors have leaks;
- power factor of compressor 7 is very low (0.6);
- a big variance exists in process variables (pressures, temperatures) for the seven cooling circuits;
- not enough measuring equipment is installed to control the process;
- insulation has deteriorated for pipe lines and evaporators;
- the refrigeration load is too big in comparison with the cooling capacity of the primary refrigeration system;
- condensers are leaking water and are scaled.

According to manuals compressor suction pressure should be around 2.7 bar abs.(40 PSIA). At TBL they range from 1 (15 PSIA) up to 3.4 bar (50 PSIA). For compressor 4, 6 and 7 suction pressures are much lower than rated ones. This means that not enough ammonia is leaving the evaporators and therefore entering the compressors, leading to a low efficiency of the compressors.

For good evaporization evaporators (shell and tube heat exchangers) should be around three quarters full with ammonia. The levels of the evaporators range from less than half full up to totally full. Also this leads to lower efficiencies. The level indicators were never checked, because a thick layer of dust had to be removed before checking.

For a good control of the primary refrigeration system it should be possible at least to check compressor suction and delivery pressures and temperatures. At TBL only for suction and delivery pressures measurement equipment is installed. Thermometers for suction and delivery temperatures are broken or missing. The problems occurring for this reason can be illustrated with the following example. Because the ammonia system is leaking ammonia, recharging has to be done relatively often. An undercharge is usually detected by looking at the temperature difference between the matching saturation temperature of the suction pressure and the actual suction temperature. When the difference is too high, i.e. when the suction ammonia is too much superheated, the system must be recharged. Functioning thermometers on suction side are not installed, which makes efficient control very difficult.

Temperature in the main cold spirit tank is fluctuating heavily and is most of the time too high. In principle a control system switches off a (number of) compressors when the desired temperature has been reached. Because this temperature is never reached, compressors are running continuously. Causes for both findings are:

- Wort cooling during wort processing is a too heavy load for the present situation.
- Sometimes only three out of seven compressors are running, because the others are under repair. Then the refrigeration load is far to big.
- The refrigeration load is too big in general because an increase of load (explained later).
- The primary refrigeration system is not working efficiently.

- ECO: improvement of maintenance and recording of energy related data of primary refrigeration

Improvement of maintenance on the primary refrigeration system and an improvement of recording equipment is necessary, so that energy efficient control is possible. This cannot be quantified in terms of savings and costs, but is believed to be very important.

Secondary/tertiary refrigerant distribution

- findings

Most pipe lines leaving the cold and warm spirit tanks are very rusty and flanges are leaking. In the fermenting rooms glass windows are in the spirit pipe lines and a lot of rust can be seen in the spirit. Besides, insulation of a part of the pipe lines has deteriorated or is missing.

- ECO: insulation of secondary/tertiary spirit pipe lines

Insulation of spirit pipe lines has deteriorated at many places because of leaks and condensate. Most of the insulation is soaked, so that its insulation capacity has diminished substantially. Priority has the following equipment to be insulated first:

- pipe lines in cooler room 3;
- pipe lines to evaporators;
- around the valves near the main spirit tanks;
- pipe lines to the old vertical fermenters outside;

Other insulation should also be replaced:

- Insulation of the main tanks, which is cracked.
- insulation of most evaporators, which is cracked. This insulation should be removable, so that the evaporators can be cleaned now and then. Up to now this has never happened.

- cost benefit analysis

An uninsulated 4 inch thick spirit pipe line of -3°C gains 1.3 MWh per meter pipe line per year. (Appendix D3e).

Savings: 1.2 * 150 * 48,000 = 8.6 million TSh/yr = US$ 17,000 with
1.2 = 90% of energy gains per meter pipe line [MWh/m,yr];
150 = minimum assessed length of uninsulated or badly insulated pipe lines [m];
48,000 = average costs for refrigerant energy [TSh/MWh].

Costs: 150 * 4,000 = 0.6 million TSh with
150 = minimum assessed length of uninsulated or badly insulated pipe lines [m];
4,000 = average insulation costs with styropor for various pipe sizes [TSh/m].
Foreign currency component: 100%

Payback time: less than one month.

It can be concluded that in general insulation of spirit pipe lines is much more profitable than insulation of steam and condensate pipe lines, because
- operating times are longer for spirit pipe lines;
- specific cooling costs are higher then specific steam costs;
- spirit pipe lines are thicker and longer;
- insulation for spirit pipe lines is much cheaper than insulation for steam pipe lines.

- ECO: tightening leaks in spirit pipe lines

- cost benefit analysis

In the present secondary/tertiary refrigeration system many leaks exist. This can be made clear by the yearly purchase of make up spirit: 450 drums of each 1 barrel (=160 l), which cost 48.2 million TSh (US$ 95,000). This is about 15% of total refrigeration costs.

- ECO: repiping of the refrigeration system

Most pipe lines are very rusty and leaking. The best would be to replace the whole refrigeration piping system.

End users

Wort cooling during wort processing (paraflow)

Wort cooling during wort processing influences steam, water and spirit consumption, so this subject could be in all sections dealing with the respective energy subsystems. However, the subject is dealt with in this chapter, because the influence on refrigeration costs is most important.

- theory

An important way of reducing energy consumption at a brewery is heat recovery in the brew house. The most important two ways are heat recovery from vapour during wort boiling and heat recovery from wort, which has to be cooled down after boiling to fermenting temperature. At TBL only the second way has been implemented. The first option has very high initial investment costs, so is not treated here.

Wort is cooled down from about 85°C to 10°C, which is the temperature needed for fermentation. This cooling is done with a plate heat exchanger, which has two parts. In the first part wort is cooled down by heat exchange with water. After this, the wort temperature is usually about 40°C. In the second part the wort is cooled by heat exchange with chilled spirit.

Cooling should be done as much as possible with water, because:

- Energy transferred to water will reduce energy consumption because the produced warm water can be used for mash, sparging or cleaning water.
- Energy transferred to spirit will increase energy consumption, because the spirit has to be cooled down again to be used again.
- The calculated spirit cooling costs are more than twice as high as steam costs.
- Big spirit flows to the wort cooler cause an increase of temperature in the spirit main tanks. This again causes higher than permitted temperatures in the conditioning and fermenting rooms.

So in this view the water flow to the heat exchanger should be as big as possible. However, only a limited amount of water is needed in a brewery. Especially at TBL it would be a waste to drain water, because quite often the brewery suffers from water shortage.

- measurements

Several measurements were done on the wort cooler. A big spreading of the measured parameters was found. Two extreme measurements are shown in table 14.

Table 14 Measurements at the wort cooler

variable	measurem. 1	measurem. 2
temperature of incoming wort [°C]	83	76
temperature of wort after water cooling [°C]	32	49
temperature of wort after spirit cooling [°C]	11	11
temperature of water before cooling [°C]	31	31
temperature of water after cooling [°C]	55	72
wort quantity [m³]	22.6	23.5
water flow [m³/hr]	25	10
duration [min]	86	100

An energy balance can be set up: wort energy decrease = water energy increase + spirit energy increase. Wort and water energy decrease/increase can be calculated. Then spirit energy increase can be obtained by substraction of the former two energy changes. See table 15. Extra needed data besides the table:

ρ_{wort} = 1,050 [kg/m^3];
c_{wort} = 3.80 [kJ/kg°C];
ΔQ = $V*\rho*\Delta T$ [GJ/hr] with
ΔQ = energy flow [GJ/hr];
V = volume flow [m^3/hr];
ρ = density [kg/m^3];
ΔT = temperature difference [°C].

Table 15 Energy balance for the wort cooler

variable	measurem. 1	measurem. 2
ΔQ_{wort} [GJ/batch]	6.5	6.1
ΔQ_{water} [GJ/batch] $\Delta Q_{refr.}$ [GJ/batch]	4.1 2.4	2.7 3.4

Table 15 shows that for the batch during the second measurement 50% extra spirit energy is needed in comparison with the first measurement.

The causes for this are:

- Different operators do different things. Everything is controlled manually.
- The thermometer for measuring water temperature after heating is broken. This makes control by operators difficult.
- Often cold water supply is not enough, because the cold water (supply) tank is empty. This tank is supplied by the brew water tank on the brewery roof. Since this water is supplied by gravity, the incoming flow into the cold water tank is not enough to supply the wort cooler. The cold water tank as well as the brew water tank on the brewery roof were dimensioned for one brew line, as it used to be before 1984.

Before it was already stated that wort cooling has a substantial impact on the temperatures in the main secondary spirit tanks. The following calculation underlines this statement:

Yearly refrigeration load:	7,190 MWh;
Average load per second (operating hours 8,600 hr):	836 kW;
Wort cooling load per second (batch 1):	465 kW;
Wort cooling load per second (batch 2):	567 kW.

The wort cooling load is heavy in comparison with the total average load. Therefore it is important to reduce the spirit flow during wort cooling by increasing the water flow.

- ECO: improvement water supply for the wort cooler

A solution is a direct pipe line and a pump with on/off control from the pump house to the cold water tank. In this way the slow filling of the cold water tank by gravity is bypassed.

- cost benefit analysis

Savings are difficult to asses, because it is unknown in how many batches per year water supply is not enough. A rough estimate can be made though. It is assumed that the average wort temperature after water cooling is reduced from 40°C to 35°C.

Savings in MWh per year:
reduction of needed energy in spirit = increase of energy in water cooling.
32,000 * (40-35) * 3.8 = 610 GJ/yr with
32,000 = cooled beer per year [tonnes/yr];
(40-35) = temperature increase water after cooling [°C];
3.8 = specific heat of wort [kJ/kg°C].
Savings in TSh per year:
610 /3.6 * 38,600 = 6.7 million TSh/yr = US$ 13,000/yr with
3.6 = conversion factor GJ -> MWh;
38,600 = spirit energy costs [TSh/MWh].

Costs:

4 hp water pump/ control equipment/float valve:	440,000 TSh (source: Bedu pumps, Ede, The Netherlands)
24 m 2½" pipe line:	180,000 TSh
other costs (10%):	60,000 TSh
Total costs:	680,000 TSh
Foreign currency component:	65%

The pay back period is 1 month.

Also extra water is needed, but this is not included in the costs, because in the next ECO a purpose for this water is found.

Extra needed water: $610 * 10^9 /(4.2 * 10^3 * (60\text{-}30))/1,000 = 4,800$ tonnes with
$610 * 10^9$ = increase of needed energy in water [J];
$4.2 * 10^3$ = specific heat of water [J/kg°C];
(60-30) = water temperature increase [°C];
1,000 = conversion factor kg -> tonnes.

- ECO: water flow through wort cooler also to mash water tank

At the moment, water leaving the wort cooler is going to the paraflow tanks on the bottling hall roof. From there it is pumped back to Hot Water Tank 1 (HLT 1), which contains sparging water. The energy balance of the hot water system (appendix D2b) shows the inconveniency of the situation. About 37,000 tonnes of water per year is needed to cool wort. Approximately 40% of this water (14,000 tonnes) can not be used as sparging water and is drained. This is a major energy loss. Warm water is also used for the mashing process. At present this water is obtained by heating cold incoming water with steam. So a solution is to lead the pipe line from the paraflow tanks on the bottling hall roof also to HLT 2 (mash water tank). The needed mash water per year is around 19,000 tonnes. So the presently drained water quantity of 14,000 tonnes is almost enough to supply the mash water tank. In the former ECO it was suggested to use around 4,800 tonnes of water extra for wort cooling to save refrigeration costs. This water temperature will drop from around 60°C to 55°C due to losses. This amount of water, together with the drained water will be enough for the mash water supply.

- cost benefit analysis

Per year 19,000 tonnes of 50°C water is needed for mashing. At present the amount of yearly drained water is 14,000 tonnes of around 55°C.

The energy savings are the costs of steam for heating up mash water from 30°C to 50°C, which is not needed any more. Also 14,000 tonnes of water is saved.

Savings:
Energy: 833 * 12,000 = 10 million TSh/yr with
833 = steam needed for mash water heating (see appendix D2a) [MWh/yr];
12,000 = steam costs [TSh/MWh].

Water: 14,000 * 173 = 2.4 million TSh with
14,000 = saved water per year [tonnes/yr];
173 = water costs [TSh/yr].

Total savings: 12.4 million TSh/yr = US$ 24,000/yr

Costs for installing a new pipe line and float valve:

12 m 2½" pipe line	90,000 TSh
water float valve	100,000 TSh (assessed)
other costs (10%)	20,000 TSh
Total costs	210,000 TSh

Foreign currency component: 50%

Pay back period: less than one month.

- ECO: automatic control of wort cooling

The paraflow should be controlled automatically to prevent mistakes by the operators. The consequences for this mistakes are costly. This improvement is included in the refurbishment project of SAB. Costs and savings are unknown.

Fermenting vessel cooling

Fermenting vessel cooling consumes relatively much electrical energy in comparison with the final load. Reasons are the use of intermediate heat exchangers and therefore many pumps (See appendix C5b). Almost as much electricity is used for the pumps as for refrigeration itself.

In the writers opinion intermediate heat exchangers used to be applied to have a tertiary spirit which was not poisonous. When vessel jackets are leaking spirit into beer vessels, this won't have any serious consequences for the customer. **At TBL also industrial methylated spirit is used as secondary/tertiary spirit, which might be very dangerous.** For the old vertical fermenters and the old fermentation room 1 secondary refrigeration is used, but not for the new vertical fermenters (CCT's) and fermentation room 2.

- ECO: removal of spirit heat exchangers

When for tertiary refrigeration also poisonous spirit is used, the heat exchangers might as well be removed. Then chemical analysis has to be done before tasting to guarantee safety.

- cost benefit analysis

Appendix C5b gives a clear vision of the situation of fermentation room 1. Secondary spirit exchanges cold with tertiary spirit. This spirit is stored down stairs in a so-called attemporating tank. From this tank spirit is circulated with the top attemporating tank on the top floor of the main brewery building, where the fermenting rooms are situated. Again from this tank spirit is recirculated by three pumps with the users. This system uses six pumps while one pump, like for fermenting room 2, could do the job.

When the heat exchangers and pumps for tertiary refrigeration are removed the following savings can be reached:

Savings:
electricity costs of five pumps with a total horse power of 29 (22 kW). Assuming an 80% utilization factor and 8,600 operating hours per year, the yearly electricity savings are:
0.8 * 22 * 8,600 * 52 = 7.9 million TSh/yr = US$ 15,000/yr.

Costs:
Pipes and fittings: unknown, but certainly much less than the yearly savings

Again appendix C5b can be used to explain the connections for the old vertical fermenting vessels. Secondary spirit exchanges cold with tertiary spirit. This spirit is stored in a buffer tank. From this tank the spirit is pumped to the old vertical fermenters. The present three pumps can be substituted by one, which pumps secondary spirit straight to the old vertical fermenters.

Savings:
electricity costs of 2 pumps (10 hp = 7.5 kW each):
0.8 * 2 * 7.5 * 8,600 * 52 = 5.4 million TSh/yr = US$ 11,000/yr.

Costs:
Pipes and fittings: unknown, but certainly much less than the yearly savings.

Another opportunity is to mothball the old vertical fermenters. Total fermenting capacity is around 20,000 hl. With the production in 1993 of 300,000 hl and an average fermenting time of 10 days, this means a capacity utilization of approximately 40%. When the bad condition of the old vertical fermenters and their scarcely use are considered, it may be better to stop their activities.

Savings:
electricity costs of 3 pumps:
0.8 * 3 * 7.5 * 8,600 * 52 = 8.0 million TSh/yr = US$ 16,000/yr.
electricity cost of primary refrigeration: this amount is neglected, because the old fermenters are hardly used.

Costs: none

green beer cooling

- ECO: green beer cooling by plate heat exchanger

This cooling is now done by increase of the spirit flows through the vessel jackets of the fermenting vessels. A better option is to use a plate heat exchanger like before, because

- Heat transfer of plate heat exchangers is more efficient than vessel jackets, so less electricity for pumping will be needed when plate heat exchangers are used.
- When beer in the vessels in fermentation room 1 and 2 is cooled to 4°C, more heat will be lost by infiltration of the environment, which has a temperature of about 10°C. The cooling can take up to 3 days.

Savings are difficult to assess and are not calculated here.

Air cooling

- findings

Control for this cooling process is not working. Thermostats are present in the cooled rooms, but out of order according to the technical personnel. The air coolers are running continuously besides a short period at night, when they are defrosted. The spirit control valves are bypassed. At the present situation this is not a big problem, because temperatures can't even reach the required ones. Doors of cooled rooms can not be closed and many cooled rooms have holes in the walls.

- measurements

The air inflows (=outflows) to the cooled rooms and related parameters were measured and are displayed in appendix D4a. With the help of the psychometric chart in appendix D4b the net energy inflow can be calculated. The net energy inflow is the energy quantity of air going out of the cooled room subtracted from the energy of the incoming air. For the filter room air flows could not be measured and were assessed on basis of its size. Probably the energy flow is bigger than the assessed one. One door of the filter room does not close properly and all three entrance doors are left open quite often.

When looking at the net specific energy flow (per m^3 volume of the cooled space) in appendix D4a, some observations can be made:

1) the new cold rooms (6,7,8) are in better condition than the old ones (2,3,4);
2) the fermenting rooms, the bright beer room and the cold room corridor consume relatively much energy.

(Possible) causes for that are:

1) cold room 1 up to 4 are situated next to each other and are interconnected by doors. During the measurement all these doors were open, while room 1 is not functioning. Probably this was done to get a more uniform temperature in the cold rooms. So rooms 2 up to 4 were also cooling room 1. Besides, the exit door in room 1 doesn't close properly and holes can be found in the walls of room 2 and 3
2) - Fermentation room 1 has holes in the walls. One feels the cold when standing on the roof. Besides it has a huge vent duct.
   - The surface temperature of the incoming air duct to the air cooler for fermentation room 2 was 16° C, while the room temperature was 10° C. This is not a measuring error. It is suspected that this air duct contains a hole where hot air is intruding. A second reason is the bad closing of the double doors of fermentation room 2.
   - The doors of the bright beer room don't close properly.
   - The surface temperature of the incoming air duct to the air cooler for the corridor was 16° C, while the ingoing air temperature in the corridor itself was 4° C. Also here it is suspected that this air duct contains a hole where hot outside air is intruding. Besides, the door between the corridor and the filter room is always open, because hoses have to go through.

Another observation is the low temperature difference between in and outgoing air, implying that cold transfer from spirit to air is inefficient.

- ECO: leak tightening in the air cooled rooms

In principle all vessels in the fermenting room are closed vessels and CO_2 is leaded away through pipe lines. Unfortunately CO_2 piping has been removed at some places so that CO_2 is disposed in the fermenting rooms. **Therefore it is very important, when leaks are tightened, that CO_2 pipe work in the fermentation rooms must be repaired to prevent people dying from oxygen shortage.**

A calculation was done to assess the expected losses through walls and ceilings of most cold rooms when losses through holes and doors are not considered. The result is shown in appendix D4c. Losses through walls and ceilings range from 1% (corridor) up to 14% (cold room 6/7/8) of the total net energy inflow. So 86% up to 99% of the energy inflows are due to necessary and unnecessary open doors, not decently closing doors and leaks in the walls. An assessment is that at least 40% of this energy can be saved by better instruction of the personnel (funga mlango!), tightening of leaks, repairing of doors and air ducts. This is a saving of approximately 2000 MWh per year of energy in the airflows.

- cost benefit analysis

Savings: 0.95 * 0.4 * 5180 * 47,600 = 95 million TSh/yr = US$ 190,000/yr with
0.95 = fraction of air cooling load which is lost due to holes and open doors [-];
0.4 = fraction of losses which is assessed to be saved [-];
5180 = total air cooling load [MWh/yr];
47,600 = air cooling costs [TSh/MWh load].

Costs of repair: unknown, but certainly much less than the yearly cost savings.

Pay back period: very short.

Fortunately a replacement of all cold room doors has been proposed in the refurbishment plan of SAB.

- ECO: insulation of air ducts in air cooler rooms

- cost benefit analysis

Air duct insulation in the air cooler rooms only exists at the air ducts for the air coolers for fermentation room 2 and the filter room. This is very strange. The surface temperature of the air duct for fermenting room 2 under the insulation was 16° C and the ambient temperature in the cooler room was 12° C. So the insulation has a negative influence.

For the (beer) filter room cooler the air duct surface temperature was about 8° C. A temperature difference with ambient temperature of 4° C is so small that costs of energy losses will never be large enough to justify the use of insulation.

So insulation of air ducts is not feasible

- ECO: switching off cold rooms

In 1993 total production was about 300,000 hl. The average conditioning time is two weeks and the (working) cold room capacity is around 50,000 hl. This means a capacity utilization of 25%. This is very low. During the whole year all cold rooms are air cooled. When beer is stored as much as possible in the same cold rooms, then for instance cold room 2, 3 and 4 can be switched off (about 35% of the total conditioning capacity).

- cost benefit analysis

Electricity cost savings by switching off cooling for rooms 2, 3 and 4 :
77.5 /1,000 * 8,600 * 47,600 = 32 million TSh/yr = US$ 62,000/yr with
77.5 = assessed air cooling load of room 2,3,4 (see appendix D4a) [kW];
1,000 = conversion factor kW -> MW;
8,600 = operating hours per year [hrs/yr];
47,600 = air cooling costs [TSh/MWh load].

Costs: nil.

refrigeration system in general

- ECO: repair of controls

Controls of the ammonia system as well as for the air cooling system should be replaced. This measure is already included in the SAB refurbishment plan. Savings are very difficult to assess.

- ECO: use of speed controlled pump motors

Spirit pumps for air cooling and vessel jacket cooling are running continuously throughout the year, irrespective of the actual loads. When for instance utilization of wort cooling during fermentation is very low, returned spirit has almost the same temperature as the forward spirit flow. Therefore speed controlled pump motors would be a very good option. At the moment the refrigeration load is often too big, so that pumps have to run continuously. When the previously suggested measures are applied this won't be the case. Although no exact savings can be indicated, this option can be very feasible in the future.

5.3.5 Improvement of the water system

As stated before specific water consumption is very high in comparison with other breweries. It is suspected that actual flows are smaller than measured flows. Causes for that can be:

- Overflows of brewery roof tanks (brew and general purpose water) and the bottling water tanks are leaded back to the main water tanks. So this water is passing the meters, which are measuring bottle hall and brew water consumption, twice. Nevertheless this water won't pass twice the main incoming meters, installed by NUWA. So this is no explanation for the huge water income, recorded by NUWA.

- The used water meters are only working properly when the pipe lines are full of water. When the pipe lines are less than full and mixed with air, they might record to much. This cause has a good chance:
  - Pressures of incoming water from NUWA is often too low, so that pipe lines might not be full.
  - Water pumps used by TBL to pump treated water to their destinations are also often running when the supply tanks are almost empty. They are sucking a lot of air too.
- Main water tanks have big leaks. One of the water tanks under the group store already proved to have leaks and is under repair.

The first option seems very likely and can be explained by the following:
In paragraph 5.1 a relation was found between capacity utilization and water consumption (See figure 17). The found relation was actually that water consumption dropped with increasing capacity utilization. This would be impossible unless the following is the matter: in case of a higher capacity utilization more water is needed for the production process and therefore less water is returned unused to the main water tanks and less water is passing the meters twice.

- energy conservation opportunities

- Installation of an extra meter for recording general purpose water. At present only brew water and bottling water flows are measured. Then it can be checked if the three main flows within the brewery equal the total water inflow recorded by NUWA. Besides, this measure is also rewarding for the sake of control of general purpose water consumption, assuming it will work rightly.
- Installation or repair of level switches:
  - to prevent overflow of service tanks on the brewery roof and bottling hall roof. The level switch for the bottling hall roof tanks is certainly not functioning at the moment.

  - to prevent air sucking of pumps when the main treated water tanks near the pump house are empty or almost empty. This also saves pumping energy.
- Using high pressure cleaning equipment. This can reduce water use substantially.
- Reuse of water for the pasteurizers and cooling water for the hydraulic system of the fillers. The drained water can be cooled at a cooling tower and be used again. A cooling tower already exists, but must be repaired.

- cost benefit analysis

It is assumed that at least 80% of the water consumption by pasteurizers and fillers can be saved.

Savings:
0.8 * 130,000 * 173 = 18.0 million TSh = US$ 35,000 with
130,000 = annual water consumption of pasteurizers and fillers [m^3/yr];
173 = treated water price [TSh/m^3].

Costs:
pipes and fittings and repair cooling tower: < 1 million TSh (assessed);
electricity consumption cooling tower and pumps and purchase pump: < 2 million TSh;
Total: < 3 million TSh.
Assessed foreign currency component: 20%.

Pay back period: less than two months.

- recommendation: water consumption research

NUWA has advanced equipment to record water flows. TIRDO hired one, but a NUWA technician didn't show up to give extra instructions needed to do valid measurements. Suggested is a water consumption research, together with NUWA technicians and equipment.

5.3.6 Improvement of the compressed air system

Though no compressed air flows could be measured, still energy conservation opportunities can be indicated.

- theory

The compressed air system is displayed in figure 20. Total efficiency can be split up in efficiency of the air compressors, the distribution system and the users.

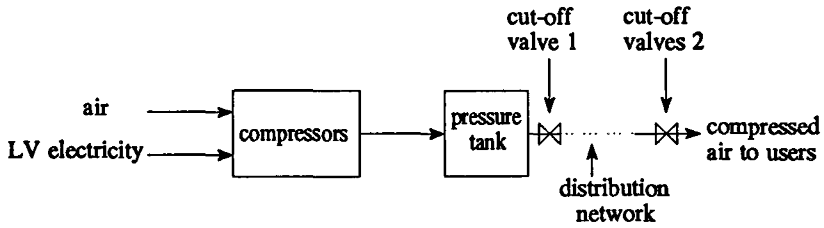


Fig. 20 The compressed air system

During a production stop in the weekend the efficiency of the compressors can be determined as follows:

1) release all pressure in the pressure tanks;
2) close valve 1;
3) switch on the air compressor until the pressure in the tank is maximal;
4) in the mean time record the electricity consumption of the compressors.

The compressor efficiency is the energy increase by pressurizing the pressure tanks divided by the electrical energy input. This is called the pump up test. In formula:

$$\eta_c = \frac{V(p_2-p_1)}{t_p P_r} \quad \text{with}$$

η_c = compressor efficiency [-];
V = receiver volume [m^3];
p_1 = initial tank pressure [Pascal abs];
p_2 = final tank pressure [Pascal abs.];
t_p = pump up time (s);
P_r = electrical power consumption of compressor [W].

The efficiency obtained from the above formula is to be compared with the values shown below, which are the best that are likely in practice (table 16).

Table 16 Practical maximum air compressor efficiencies
Source: [TIRDAF, appendix 18]

$\frac{P_1+P_2}{2}$ [kPa abs.]	efficiency η [-]	
	single stage compressor	two stage compressor
446	0.39	0.44
653	0.30	0.34
791	0.26	0.30

If the efficiency found for the tested compressor does not reach 90% of the values given above, the performance is insufficient. This can be caused by leaking valves, worn piston rings, clogged coolers or filters, loose drive belts, etc..

Energy losses due to unsatisfactory compressor performance can be derived from the difference between ideal and actual efficiency:

$$Q_l = \frac{\eta_l-\eta_a}{\eta_l} \Delta H \, P_r \quad \text{with}$$

Q_l = electrical loss [Wh];
η_l, η_a = ideal and actual efficiencies [-];
ΔH = on load operating hours per year [hr].

The efficiency of the distribution system can be determined by doing the following:

1) close all valves 2 as close as possible to the users;
2) open valve 1;
3) switch on the air compressors until pressure in the pressure tank is maximal;
4) record the time to reach a certain pressure drop in the pressure tanks.

The recorded time period within which a certain pressure drop occurs is a measure for the number or size of leaks in the distribution system. This is called the leak test. In formula:

$$q = \frac{T}{T+t} * 100\% \quad \text{with}$$

q = relative system leakage [%];
T = time on load [s];
t = time off load [s].

For well maintained systems the relative system leakage is below 10%. Energy losses are:

$$E_l = q\,\Delta H\,P_r / 100 \quad \text{with}$$

E_l = electrical loss [Wh];
ΔH = operating hours per year [hr];
100 = correction factor because of percentage [-].

The efficiency of the users could not be determined because air flows to various users could not be quantified.

- measurements

Measurements were done on one of the two air compressors. The second air cooler was idle because of malfunctioning of the inter cooler. The average results for air compressor 1 are:

Volume pressure tank: 3.8 m^3;
Compressor type: two stage.

Pump up test:

On load power consumption:	100 kW;
On load operating hours:	± 3,000 hrs/yr;
Pump up time:	83 s;
p_1 :	100 kPa abs;
p_2 :	746 kPa abs.

The calculated efficiency $\acute{\eta}$ = 0.29. According to table 16 the efficiency should be at least 0.44. Electrical energy losses per year are 140 MWh, which costs 5.6 million TSh.

Leak test:

Total operating hours:	± 5,000 hrs/yr;
Average power consumption:	88 kW;
T :	43.2 s;
t :	32.6 s.

This means that the relative system leakage is 57% while it should be lower than 10%. This means many leaks do exist, which must be repaired. Electrical energy losses per year are 250 MWh, which cost 13 million TSh.

- ECO: improvement of air compressor performance and compressed air leak tightening

Energy savings:

compressor performance improvement:	5.6 million TSh
compressed air leak tightening: (q = 57% -> 10%)	10.7 million TSh
Total	16.3 million TSh = US$ 32,000
Assessed costs:	3.3 million TSh [TIRDO, page vii]
Assessed foreign currency component:	30%.

Pay back period: less than three months.

5.3.7 Alternative energy supply

- ECO: cogeneration

Cogeneration is the simultaneous production of process steam and electricity. High pressure steam is produced to move a turbine electricity generator. The exhaust low pressure steam can be used as process steam. This is applied in some big Dutch breweries. Before making difficult calculations first the pros and cons should be analyzed. The main pro is the decrease of dependency on the unreliable electricity grid. The list of cons is larger:

- Electricity demand is rather stable. Steam demand is fluctuating heavily, because of the batch wise processing in the brew house and the many production stops in the bottling halls. When electricity demand tracking is applied, a lot of energy is lost because of the changing ratio of steam and electricity demand. When steam demand tracking is applied, a major amount of electricity still has to be purchased from the grid.
- The steam and electricity demand are probably not large enough for a profitable cogeneration application.
- Macro-economical it is not desired to apply cogeneration. More crude petroleum will have to be imported, causing a worsening of the balance of payment, while electricity is generated indigenously by hydropower.
- The installation will require high initial investments in foreign currencies.

- The installation will increase the technological complexity of plant and maintenance, which is undesirable.
- It would be wiser to start with demand management and see later about the supply side.

Beforehand the option of cogeneration is rejected because of the many draw backs.

- ECO: use of solar energy

By use of a solar collector process water can be heated up to save steam costs. Application are possible in the brew house and in the bottling halls. The application in the brew house seems less promising. Most steam is used for heating up and boiling wort. No applications in the world are known where wort is heated up by solar energy. The effects on e.g. beer taste is not known. Besides, after boiling wort has to be cooled down again for fermentation. This cooling is partly done by heat exchange with cold water. In principle the obtained hot water is sufficient to supply the hot water demand in the brew house. Water heating for washers and pasteurizers in the bottling hall seems more appropriate for an application. A rough calculation is made:

Assessment yearly average insolation in Tanzania: 250 W/m^2;
efficiency of a solar collector: 0.3;
energy need per pasteurizer and washer: 3,000 MJ/hr = 0.8 MW;
-> required collector area: 3,300 m^2 per brew line.

This would mean an area of e.g. 33 x 100 m. The new bottling hall roof is large enough to contain this collector area. Unknown is if it is also strong enough. Another advantage would be the temperature decrease in the new bottling hall, which is very high at the moment.

- cost benefit analysis

Assumptions:
- 12 hours daylight per day;
- no storage facilities are used;
- the pasteurizer and washer with attached solar collector system are used 10 hours per day for 260 days per year (total: 2600 hrs/yr).

Steam savings: 1460 * 2600 * 12,000/1,000 = 46 million TSh = US$ 89,000 per year.
Assessed installation costs: US$ 0.8 million
Pay back period: 9 years

This option is not feasible

5.4 Further recommendations

- Reorganisation of present maintenance programs and logistics department.

Observation in the company and the results of former evaluated ECO's makes it clear that lack of maintenance is probably the main cause of the bad present energy situation. A necessary step is the reorganisation of the total maintenance program and organisation. Also the logistics department has to be included in this evaluation, because good maintenance is directly dependent on the delivery of necessary spare parts. Important questions are:
- What kind and how much equipment does TBL DSM actually have?
- Which piece of equipment needs what type of maintenance?
- How long does this maintenance take?
- What is the life cycle of spare parts, necessary to perform maintenance? This questions can be answered by analysing two aspects:

  - what do manuals recommend with respect to replacement of still functioning components?
  - what is the historical experience with respect to failing of spare parts?
- What is the historical experience with respect to the delivery time of locally made or imported spare parts?
- What is the best stock quantity of spare parts, realizing
  - the length of delivery time?
  - the frequency of break down?
  - devaluation of Tanzanian shillings?
- What are the net costs for either preventive or corrective maintenance, realizing
  - how long it takes to perform preventive or corrective maintenance?
  - how much production is lost by doing either type of maintenance?
  - how much costs can be saved by good maintenance with respect to:
    - less production stops and less production losses resulting in higher production output?
    - much less energy costs per product of output (36% reduction when production capacity utilization increases from 30 to 60%)?

The answers to these questions should lead to a new set up of maintenance and logistics organisation. Records of corrective maintenance jobs have been inaccurate. It is important to record these jobs well. These records are a guidance for future maintenance and maintenance organisation. Important aspects are the number and kind of needed spare parts, needed time for the job, needed man hours and detailed description of the failure.

- Motivation of personnel

It is believed that good motivation is of vital importance for the company and for energy consumption in specific. This ranges from direct action when a hot water tank is overflowing to the correct and fast execution of maintenance. Measures have been taken before to improve motivation. These measures were not a success, partly because of corruption. The following measures are recommended:
In general:
- Substantial increase of wages and less staff welfare expenses. In 1993 the contribution of wages was 1.4% of total direct production costs. Around 700 out of 3000 employees are or will be fired in 1994. Therefore an increase of basic wages will not have a big effect on total costs.
- Direct dismissal of employees who reveal corruptive behaviour, which has a substantial proven negative effect on the company, regardless position or function.
- Improvement of the facilities of employees with respect to sanitary, food, medical care, etc..
- The introduction of a bonus system with relation to reaching planned production quantities and qualities and fast and correct maintenance jobs. The planned production must be an achievable goal.
- More openness in relation to planned activities to all employees.
- More participation of employees. In the Netherlands research has proven that a relation exists between motivation and participation of employees. Participation is absolutely lacking at TBL. Participation as applied in the Netherlands is probably not applicable in Tanzania because of the different social structure. However, more attention for the opinion of the employee is important for motivation and can help decision-making.

With respect to energy efficient behaviour:
- explaining in what ways energy can be saved;
- explaining how certain activities are very costly in relation to energy;
- explaining the costs for certain behaviour in understandable terms, e.g. opening a door of an air cooled space is like switching on 530 light bulbs of 100 Watts for the time the door is open[1];
- rewarding operators for energy efficient behaviour.

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[1] For calculation see appendix F3

- Energy management

Recording of energy data

The former evaluations of energy conservation opportunities showed that much energy and energy costs can be saved. Much effort was needed to get all needed data. For instance steam consumption was indirectly determined by assessing steam loads. It would have been much easier when water flows to the boilers or steam flows were recorded directly by flow meters. For the water system few ECO's could be pointed out, because water flows are mainly unknown. Therefore and for the sake of future energy consumption control (energy management) it is recommended to install the following meters:

- flow meters for fuel oil to boilers;
- main steam or water flow meters to boilers;
- hot water flow meter to measure hot water flow to the brew house;
- water flow meter for general purpose water in the main brewery building;
- three water flow meters to measure water flows to the bottling hall;
- separate kWh-meters for each transformer.

Furthermore a portable water flow meter can be purchased. Another option is renting one from the National Urban Water Authority.

Energy manager

Recording data must have the goal to improve the energy efficiency of the plant. At TBL it would be useful to appoint a full time energy manager. Two engineers at TBL have had courses about energy conservation and energy management and are fully capable for this function in the writer's opinion. The function of this energy manager should be the set up of a recording system. With help of this system energy conservation opportunities can be analyzed for their profitability and worked out plans can be handed to the management for approval.

- Governmental support

A reference is made to [Touss, p26]. It was stated that by means of TIRDO support is given to perform energy audits. Though calculations of TIRDO are often only rough, expected profits by energy conservation measures are so high that no more details are needed to be convincing. Nevertheless more support is needed on the area of technology information and finances as an incentive to really implement these measures.

5.5 Overview and priorities of ECO's

An overview of quantified measures is displayed in table 17. Also priorities are given. These priorities are based on the quantity of needed investment, the foreign currency component of these investments, the quantity of cost savings of the measures and the length of the pay back period.

Besides the ECO's 'increase of capacity utilization' and 'reduction of production losses', the total energy cost savings are around 300 million TSh (= US$ 590,000). This is an energy cost reduction of 1000 TSh per hectolitre, which means 30% reduction. It is assessed that when all indicated measures are taken, specific energy costs will reduce around 50%.

Not all implementation costs and pay back periods could be assessed. For the measures, for which costs could be assessed, the average pay back period is 2 months. The average foreign currency component of quantified costs is about 75%. This percentage is quite high, but foreign currency requirements as a percentage of total energy cost savings is low (13%).

Table 17 Overview of quantified feasible energy conservation opportunities

priority	Energy conservation opportunity	Savings '000 TSh	Costs '000 TSh	Required foreign currencies [% of costs]	Pay back period	page
1	capacity utilization increase 30 -> 60%	36% of energy costs per hl	?	?	?	41
2	switch off air cooling of cold rooms not used	32,000	0	0	0	62
3	mothballing old vertical fermenters	8,000	0	0	0	59
4	air cooling load reduction by building/air duct maintenance	95,000	?	0	?	61
5	decrease of production losses 16% -> 8%	8% of energy costs per hl	?	?	?	43
6	tightening leaks in secondary/tertiary refrigeration system	48,200	?	0	?	55
7	improvement power factor	21,400	?	100	?	53
8	insulation water pipe lines and tanks	14,800	1,700	100	1 month	50
9	water reuse in bottling hall	18,000	3,000	20	2 months	63
10	improvement compressed air system	16,300	3,300	30	3 months	67
11	water from wort cooler also to mash water tank	12,400	210	50	< 1 month	58
12	insulation refrigeration piping	8,600	600	100	1 month	54
13	improvement load factor transformers	8,900	3,000	100	4 months	51
14	removal heat exchanger ferm. room 1	7,900	?	0	?	59
15	improvement water supply wort cooler	6,700	680	65	1 month	57
16	condensate return mash vessel	835	220	70	3 months	48
17	tightening steam leaks[1]	130 / mm^2	20 / mm^2	0	2 months	47
18	insulation steam pipe lines[1]	2,200	4,000	100	2 years	46
19	insulation condensate pipe lines[1]	2,720	5,420	100	2 years	47
	Total[2]	304,000 [2]	?	?	?	

[1] These measures have a higher priority when safety of personnel is also considered in decision making

[2] Does not include increase of capacity utilization, decrease of production losses and tightening steam leaks

The following measures could not be quantified, but are probably very feasible measures (table 18):

Table 18 Overview of not quantified (probably) feasible energy conservation opportunities

probable priority	Energy conservation opportunity	page
1	improvement of control equipment for the refrigeration system	63
2	improvement of control equipment for the water system (level switched pumps)	63
3	automatizing control of wort cooling system	59
4	repair of cut-off steam valves	47
5	green beer cooling by plate heat exchanger	60
6	repair of steam traps	47

Not feasible or not applicable are:

Table 19 Overview of not feasible or applicable opportunities

Energy conservation opportunity	page
improvement of boiler performances[1]	44
insulation of process vessels	49
electricity peak load management	52
insulation of air ducts	62
cogeneration	67
solar energy use for the bottling halls	68

[1] Though this measure is financially feasible, the risk, when the measure is implemented, is too high

Previously mentioned energy conservation opportunities are all measures, which can be implemented on short term. Table 20 contains recommendations, for which results can only be expected on longer term, i.e. not within a year. However, these measures are important, because they will contribute to the controllability of energy (and other) costs in the future.

Table 20 Overview of overall recommendations

recommendation	page
improvement of maintenance and maintenance organisation of all sections	68
improvement of motivation of personnel	69
improvement of energy recording and purchase of energy recording equipment	70
appointment of full time energy manager	70

5.6 Causes of high specific energy costs at TBL in comparison with a western brewery

In paragraph 4.2 a comparison was made between specific energy costs at TBL and a reference brewery. After the evaluation of energy conservation opportunities an overall balance can be made up to quantify causes of difference. The reference brewery has a capacity utilization of 80% and 6% production losses. TBL has a capacity utilization of 30% and 16% production losses (1993). In figure 21 the comparison and the contribution of causes are displayed. Calculations for the various contributions can be found in appendix F4. The contribution of each cause is calculated under the

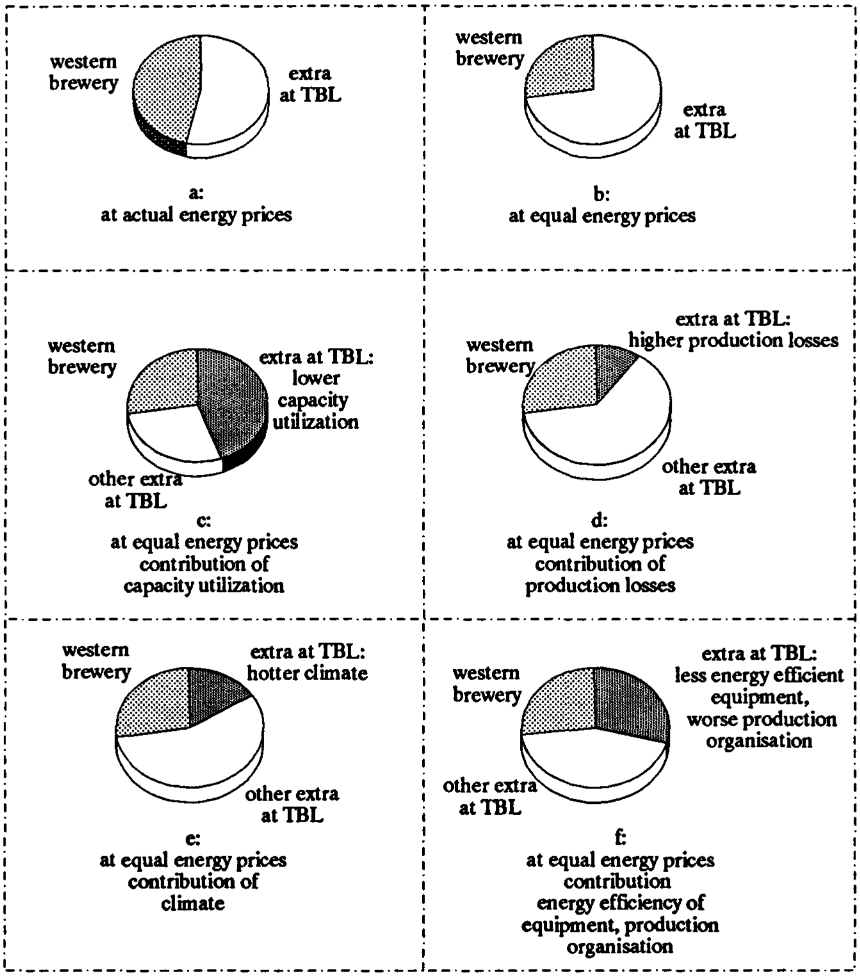

Fig. 21 Causes of extra specific energy costs at TBL in comparison with a western brewery

condition that all other variables are as in 1993. Figure 21a and b are the same as figure 16. The low capacity utilization at TBL is the main cause for the high specific energy costs. Improvement of capacity utilization from 30% to 80% would reduce these costs at TBL from almost four times as much in comparison with the reference brewery to some more than twice as much (figure 21c). High production losses at TBL (figure 21d) have not such a big influence on high specific energy costs as capacity utilization, but are still substantial.

In the calculations of the effect of the climate two causes are considered:
- less heat (fuel oil) is needed to produce hot water, because incoming water is warmer at TBL (will reduce specific energy costs at TBL);
- more electricity is needed for the refrigeration system to keep spaces at low temperature because of a hotter climate (will increase specific energy costs at TBL).

It is clear that the second cause has the biggest influence, resulting in higher specific energy costs at TBL. In paragraph 2.4, page 16, it was indicated that the influence of the climate is an independent influencing factor. Now it is believed that this is not true. The influence of the climate will be affected when e.g. cooled spaces are better maintained or when less warm water is needed in the production process.

Finally figure 21f explains the higher specific energy costs at TBL by a less organized, less maintained and less energy efficient production process. The graph is based on the total amount of energy cost reduction, which is possible by implementing the energy conservation opportunities on this area, as indicated in paragraph 5.3. In reality this cause is much more important, because not all energy conservation opportunities are treated in that paragraph and besides, not all ECO's have been quantified.

All separate causes for a higher specific energy costs at TBL, as indicated in figure 21, can not be added in one single circle graph, because the various causes are overlapping. For instance, the effects of the climate would be much smaller when cooled spaces would be better maintained (energy efficiency of the equipment).

6 Conclusions

Specific electricity and fuel oil consumption at TBL DSM is 2 up to 3 times higher than at western breweries. Specific water consumption is around 8 times higher. The cost percentage of energy is 23% of total direct production costs. At TBL specific energy costs are more than twice as high than for a comparable western brewery. So cost saving by energy conservation is very rewarding. Energy prices in Tanzania are lower than in a western brewery. When these prices would be the same, specific energy costs (total of electricity, fuel oil and water) at TBL would be almost four times as high. Energy prices in Tanzania are not increasing when the prices in US dollars are considered.

The most important cause of high specific energy consumption is a too low production capacity utilization. An increase of utilization from 30% in 1993 to 60% (a doubling of the production) causes approximately a 36% decrease of energy costs per crate of beer. Not only specific energy costs will reduce, but also specific overhead costs will decrease, resulting in higher specific profits. The main cause of the present low capacity utilization is down time, mainly caused equipment break down. A reduction of total production losses from 16% (1993) to 8% saves about 8% of energy costs per crate of beer. Another important cause is lack of maintenance, which should be improved. Insufficient maintenance is also the main cause of the low capacity utilization and high production losses. Influence of the climate would be much lower when good building maintenance would have been performed. Not enough research is done to know the exact causes of insufficient maintenance. Partly the cause is the difficulty to purchase the appropriate spare parts and wrong priorities for foreign currency assignments. Surely maintenance and spare part supply has improved and will improve during the joint venture with South African Breweries. Other measures, on the area of improvement of used technologies and production organisation, can reduce energy costs with another 28%. All indicated measures can reduce energy costs with about 50%

Not all implementation costs and pay back periods could be assessed. For the measures, for which costs could be assessed, the average pay back period is 2 months. The average foreign currency component of quantified costs is about 75%. This percentage is quite high, but foreign currency requirements as a percentage of total energy cost savings is low (13%).

For a structural improvement of the controllability of energy (and other) costs on longer term, the following recommendations are important:

- improvement of maintenance and maintenance organisation of all sections;
- improvement of energy recording and purchase of energy recording equipment;
- appointment of full time energy manager;
- improvement of motivation of personnel.

About other indicated (indirect) factors influencing energy costs no hard conclusions can be drawn, because not enough research was done on these subjects.

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[TIRDAF] TIRDO and ÅF-ENERGIKONSULT, Semi detailed energy audit at Tanzania Breweries, Dar es Salaam plant, 1990

[TIRDO] TIRDO, Electrical Energy and Demand Survey of Tanzania Breweries Ltd, Dar es Salaam Plant, April 1994

[Touss] T.J.A. Toussaint, Energy conservation in the industry of Tanzania, Report 1: The importance of energy conservation in the industry of Tanzania, an exploratory economic study , November 1994

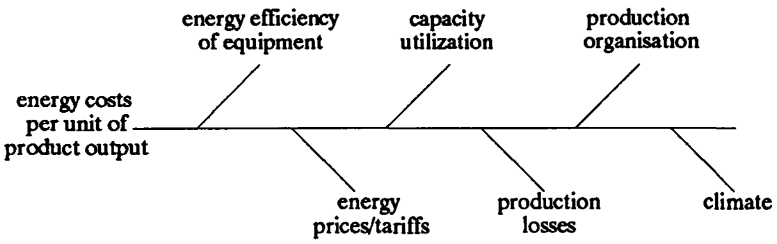
[Turner] Wayne C. Turner, c.s., Energy management handbook, 1982

[Witte] Larry C. Witte, Philip S. Schmidt and David R. Brown, Industrial Energy Management and Utilization, 1988

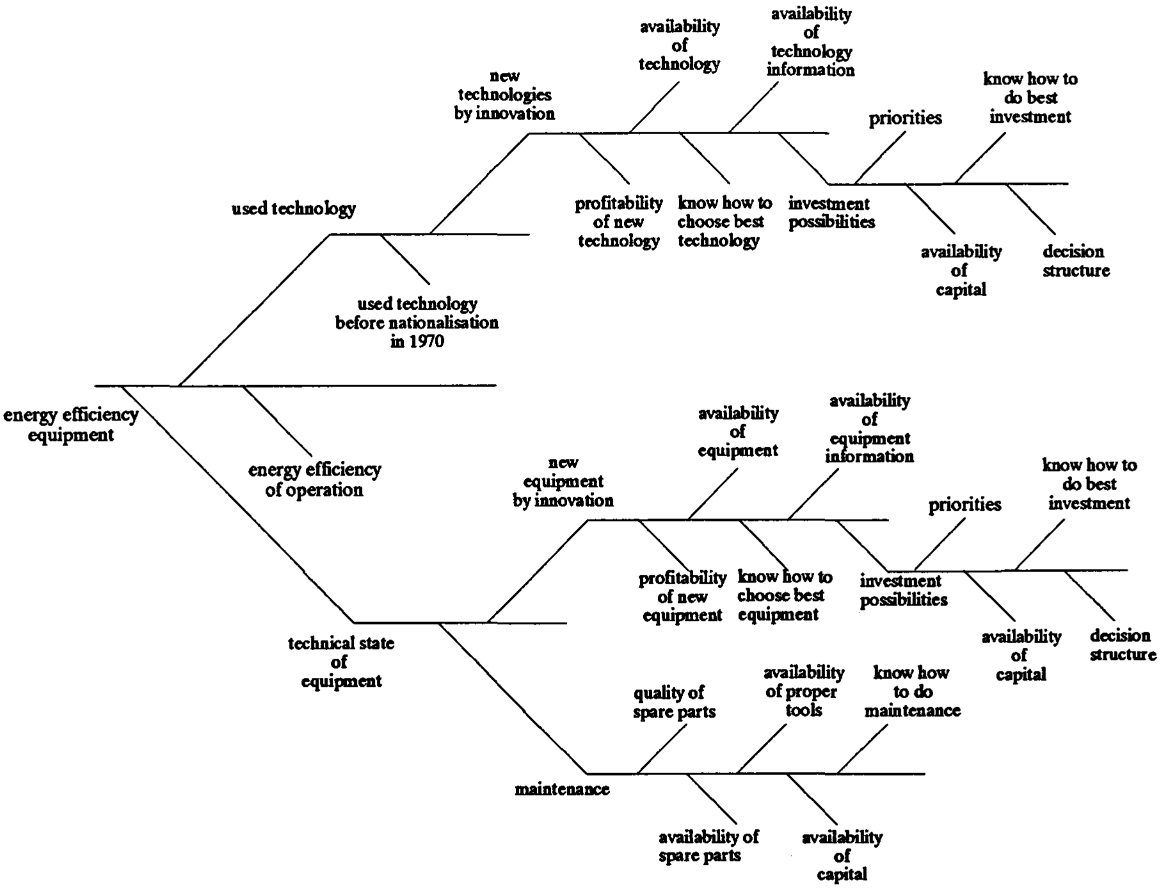
Appendices

Appendix A: factors influencing energy costs

Direct factors:

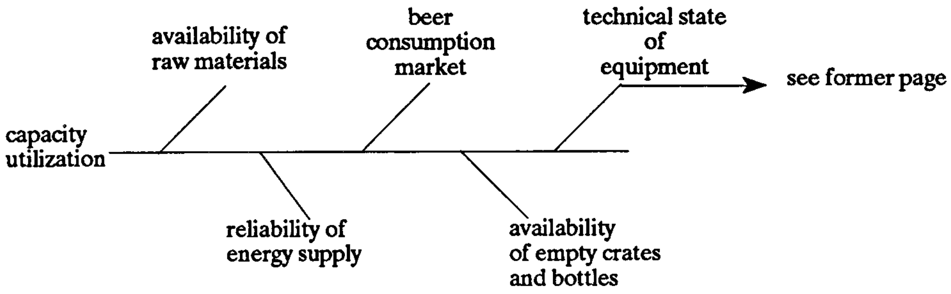


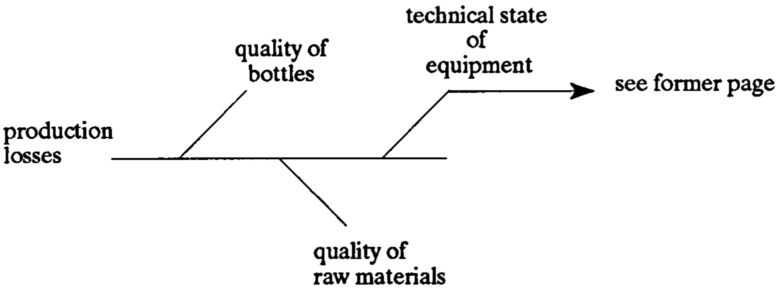
Indirect factors:

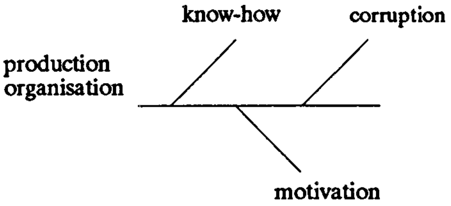


Appendix A: factors influencing energy costs (continued)

Indirect factors (continued):

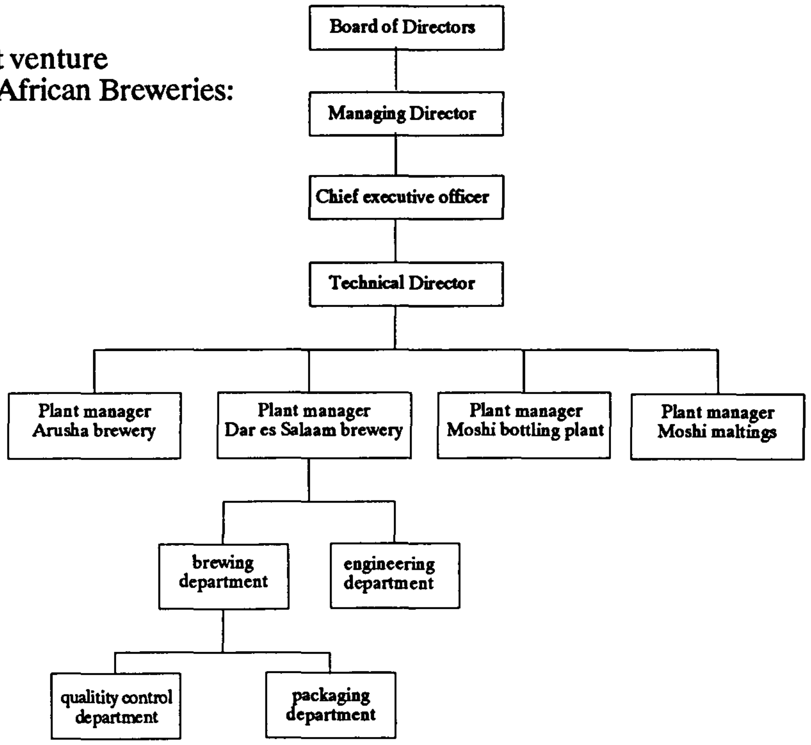




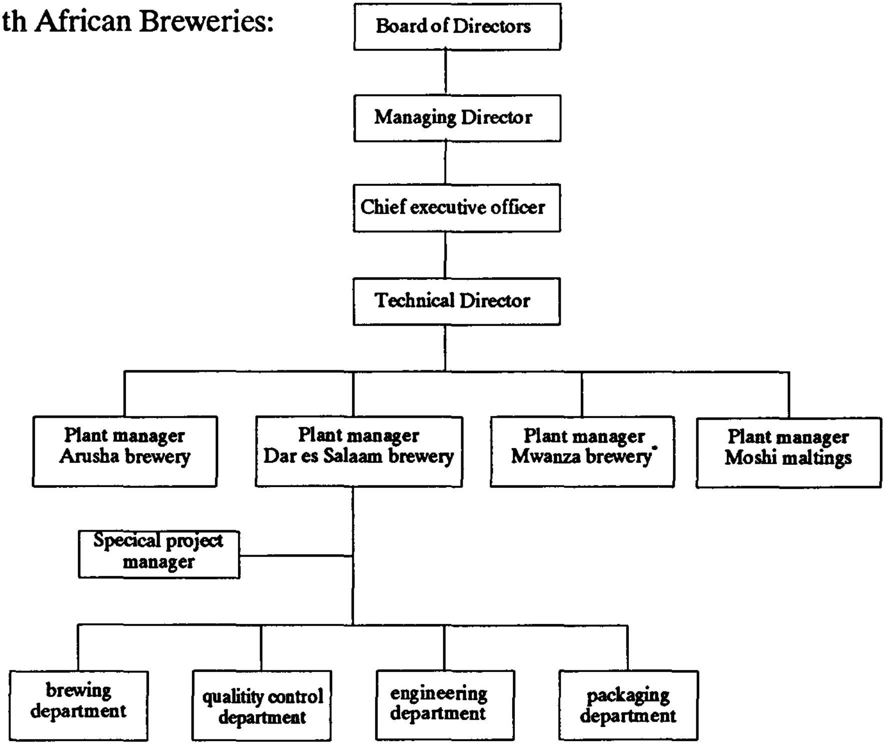


Appendix B: Organisation charts of Tanzania Breweries Ltd.

Before joint venture
with South African Breweries:

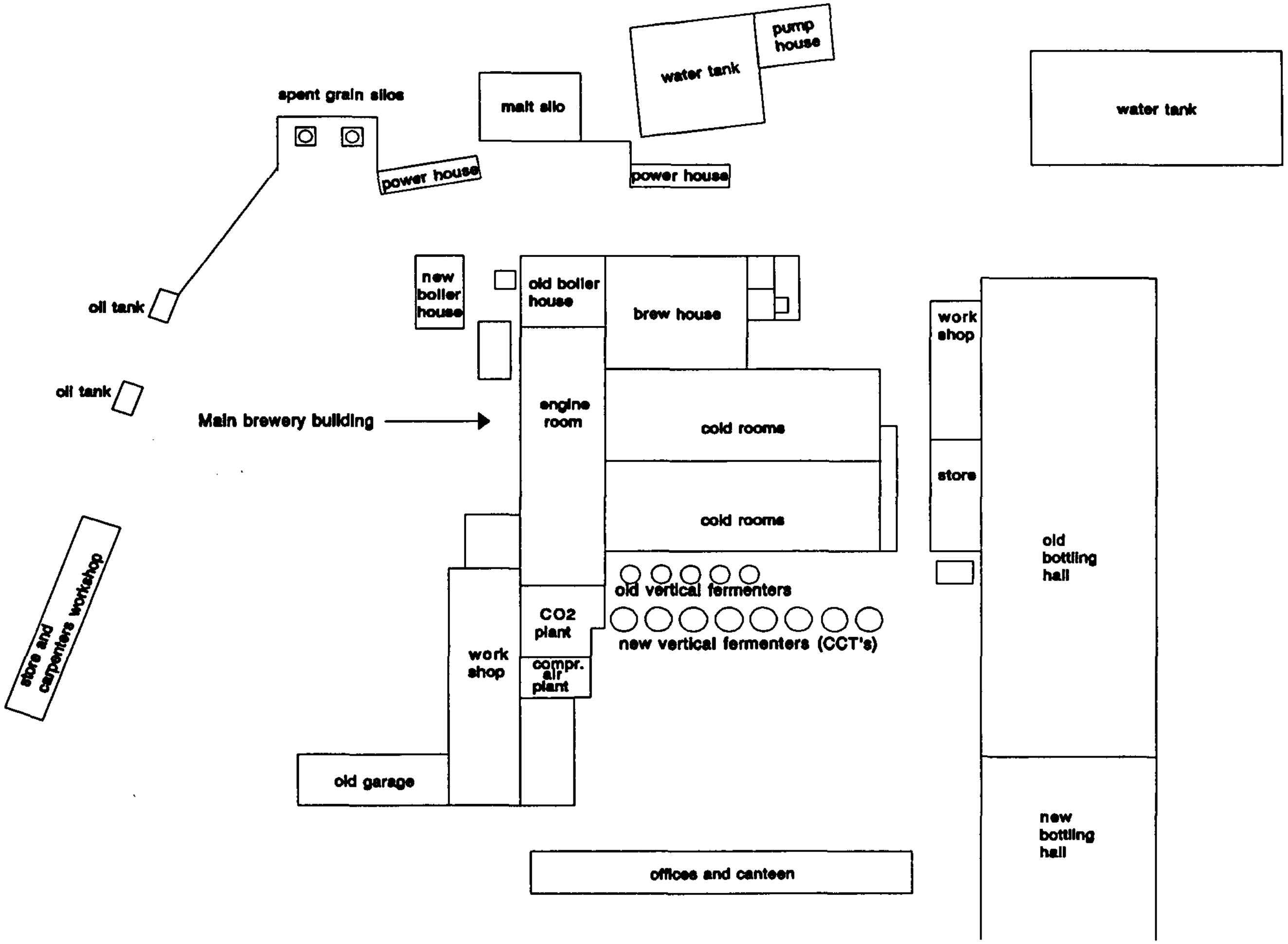


During joint venture
with South African Breweries:

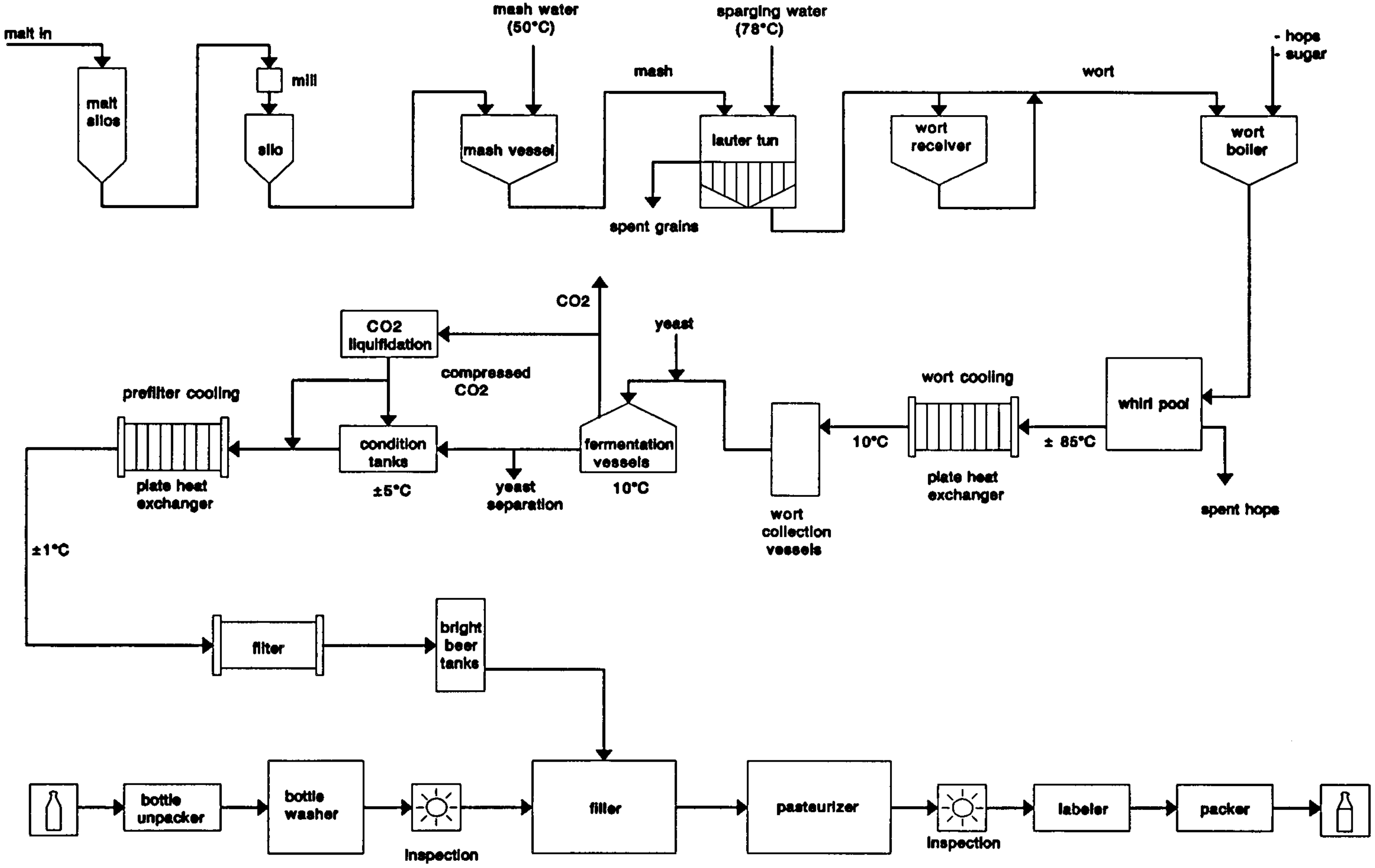


Appendix C: Drawings

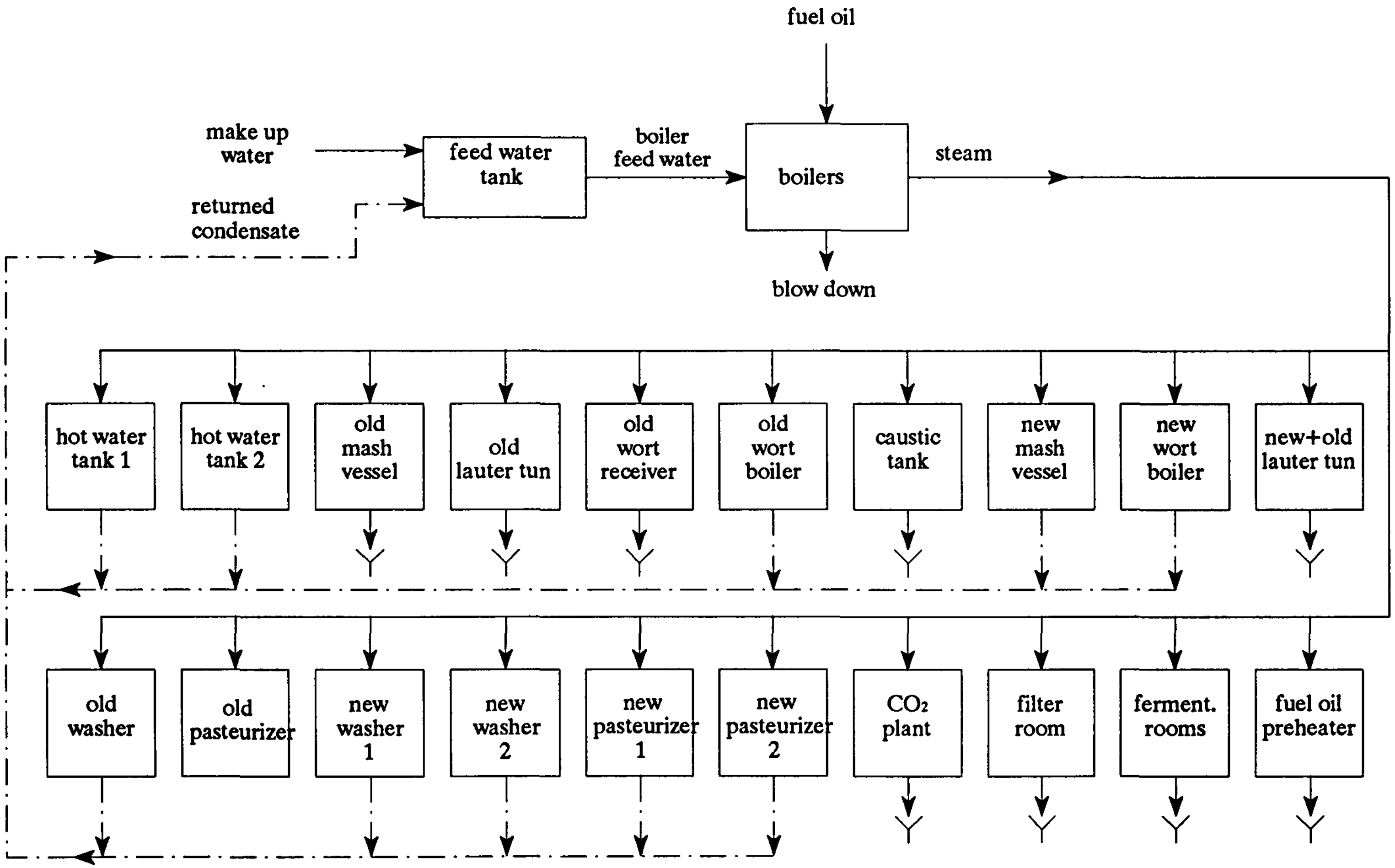
Appendix C1: DSM brewery site



Appendix C2: The production process



Appendix C3: Steam and condensate system



Appendix C4: Electricity system

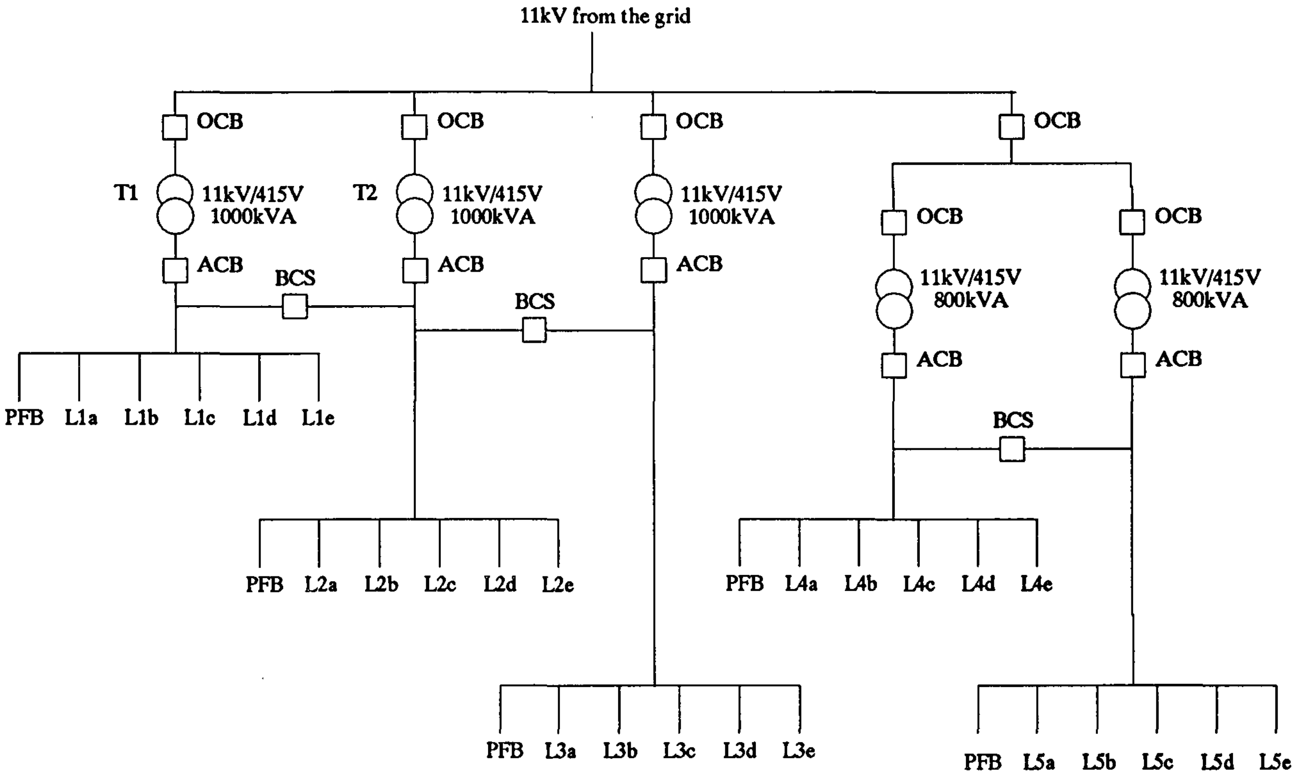
Legend

OCB = Oil Circuit Breaker
T = Transformer
ACB = Air Circuit Breaker
BCS = Busbar Connection Switch
PFB = Power Factor Bank
L = electrical Load

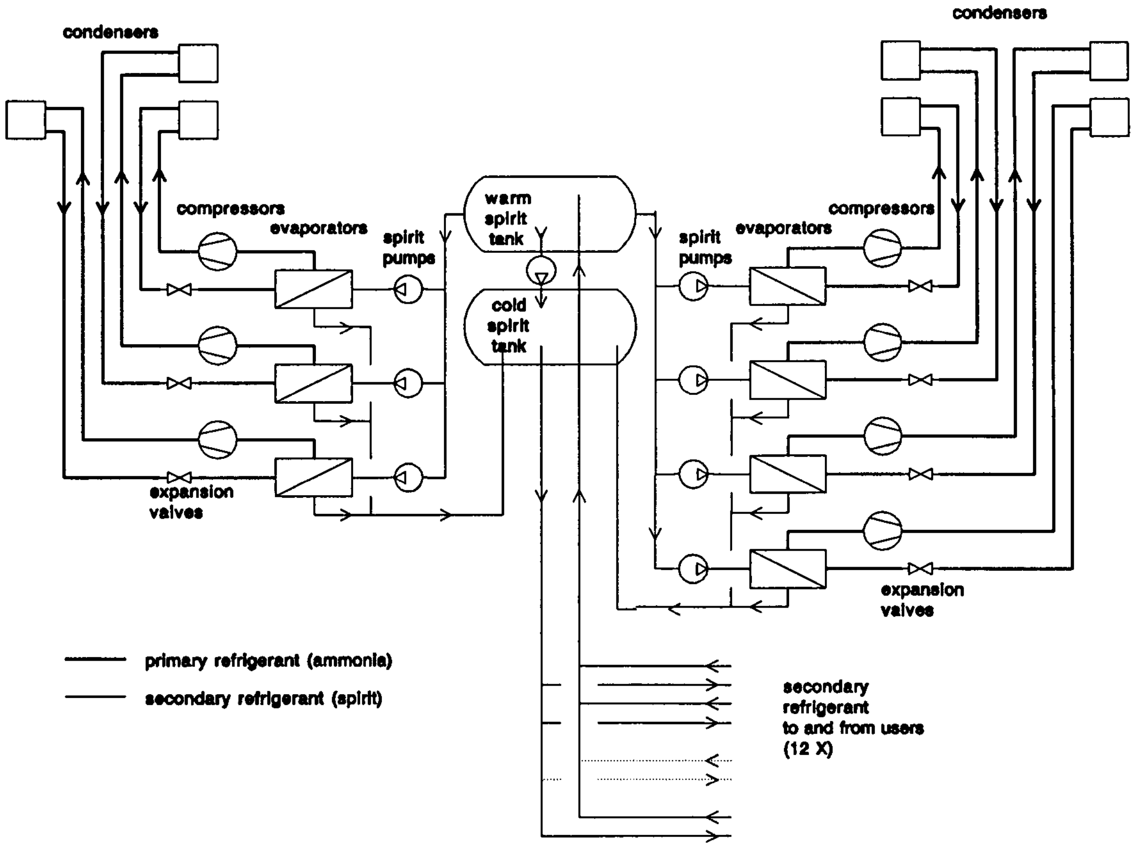
L1a = Ammonia compressor 2 and 4
L1b = Refrigeration panels
L1c = Old brew house
L1d = Pump house
L1e = Head office and old bottling hall (light)
L2a = CO_2 installation \ work shop \ administration
L2b = Ammonia compressor 1 and 3
L2c = Old bottling hall (line 1)
L2d = Boiler 1 and 2
L2e = Old brew house

L3a = Air compressor 2
L3b = Ammonia compressor 5 and 6
L3c = unknown
L3d = New brew house
L3e = silo block
L4a = New bottling hall (line 3)
L4b = Distribution office
L4c = No load
L4d = Ammonia compressor 7
L4e = No load

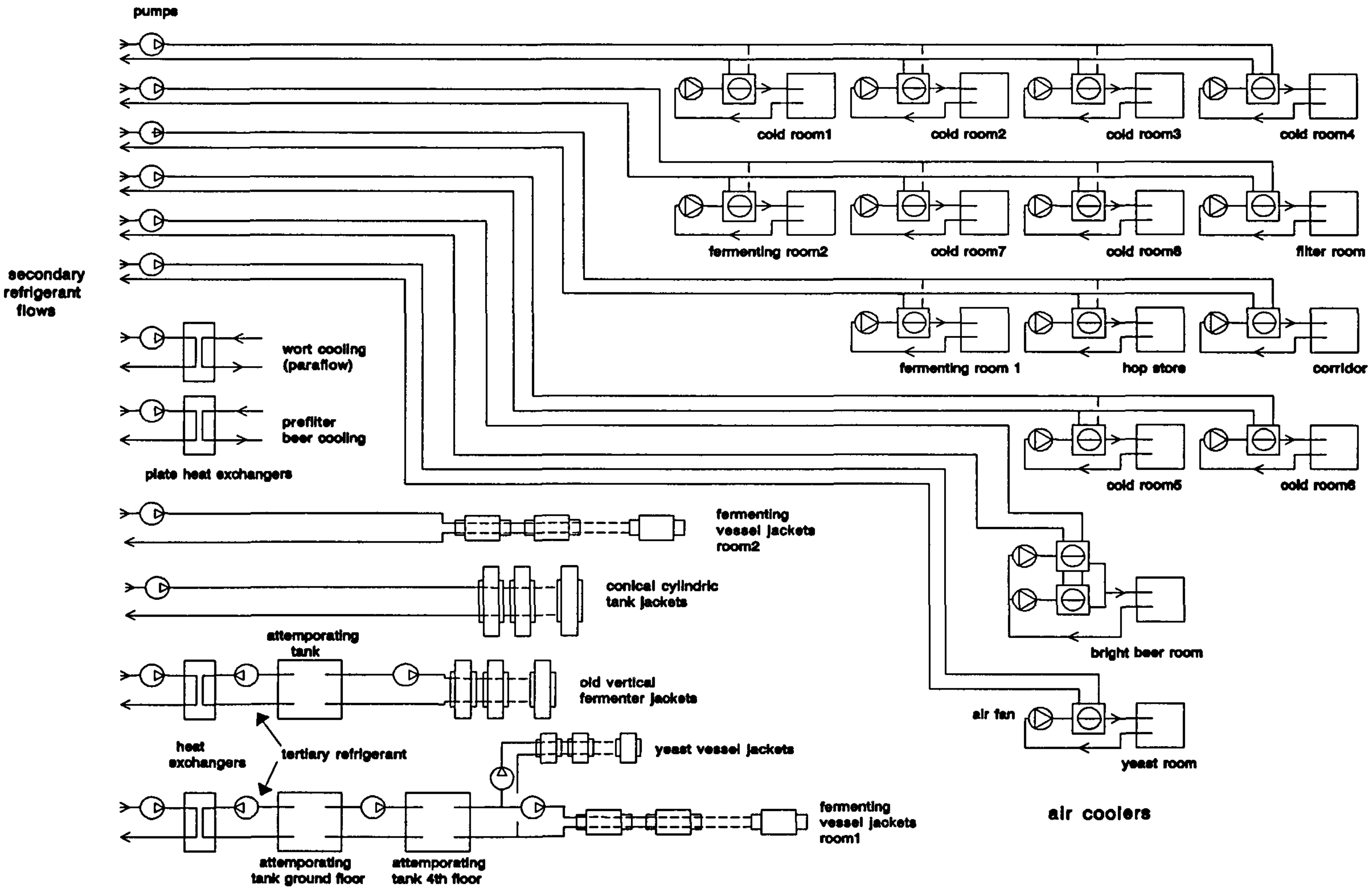
L5a = Air compressor 1
L5b = New bottling hall (line 2)
L5c = No load
L5d = Boiler 3 (out of order)
L5e = No load



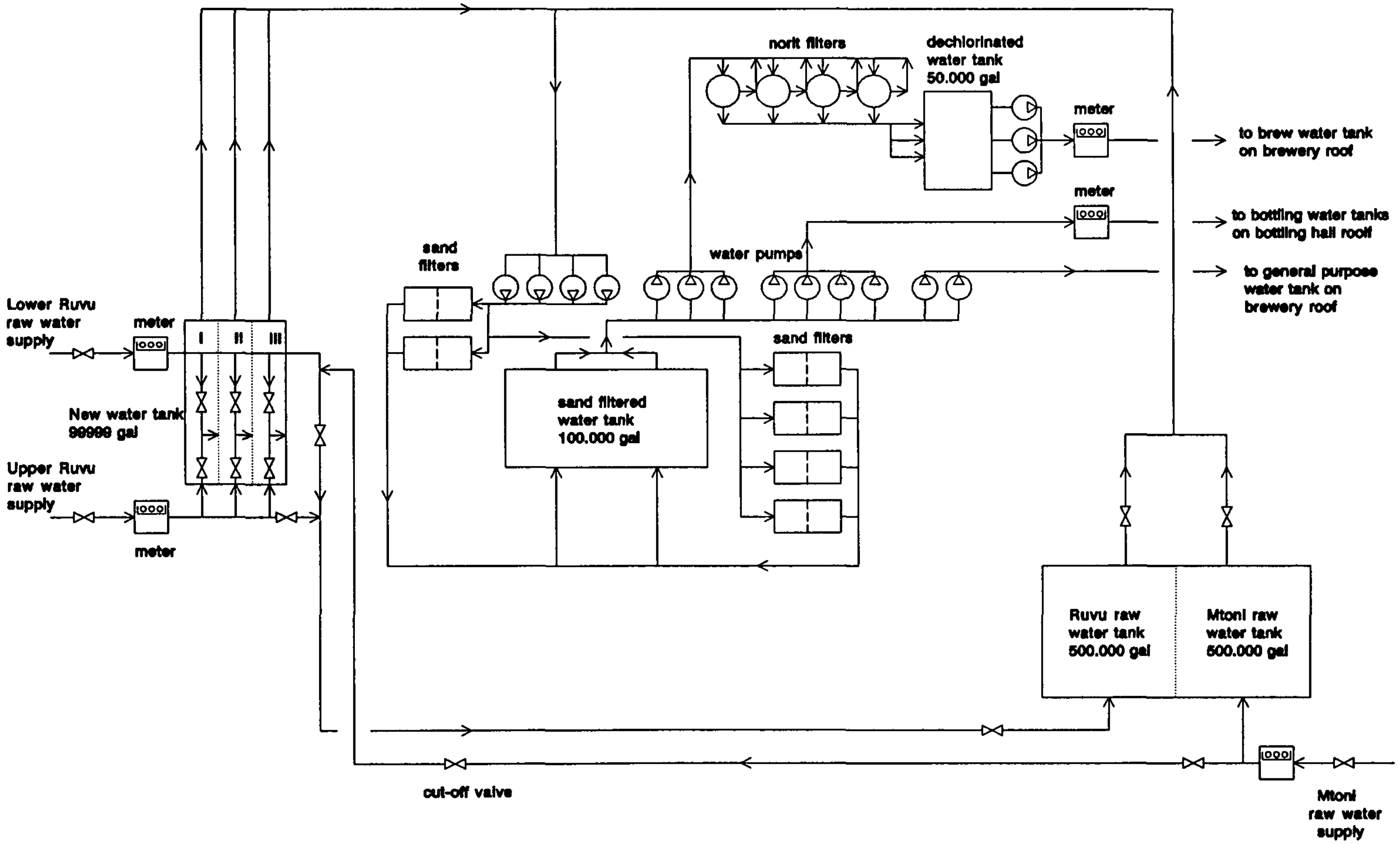
Appendix C5a: Primary/secondary refrigeration system



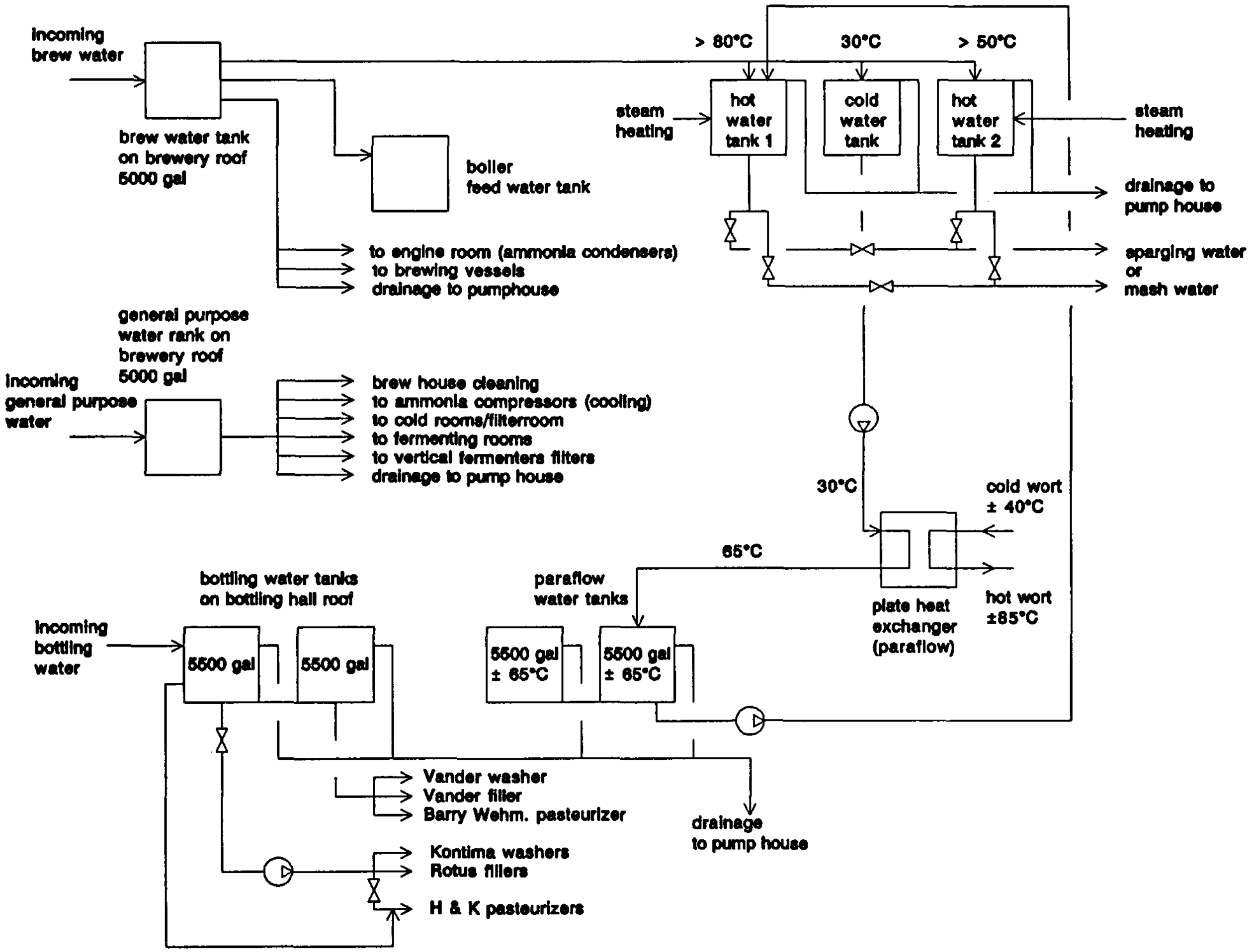
Appendix C5b: Secondary/tertiary refrigeration system



Appendix C6a: Water treatment and supply



Appendix C6b: Water supply and user system



Appendix D: Energy and mass balances

Appendix D1: Calculation of energy balances

In this appendix energy and/or mass balances are set up for the major energy subsystems. These are the steam and condensate system, the hot water system, the electricity system, the refrigeration system, the cold air system and the water system. With help of these balances the energy flows, indicated in fig. 15 (section 3.4.3), can be quantified. Unfortunately far from all flows could be quantified. The reasons will be explained in the respective sections about the separate energy subbalances.

All balances are based on energy consumption and operating times in 1993. The balances are calculated for a whole year, namely 1993. Energy of water is defined as the heat needed to heat up the water from 0°C to the actual temperature.

Measurements were in most cases done with help of measuring equipment and man power of TIRDO.

1 Energy/mass balance for the steam and condensate system

For the set up of this balance no measuring possibilities were available to measure the separate steam flows to the users. Total steam consumption was assessed with help of the efficiency of the boilers and total fuel oil consumption. For the main users steam consumption was indirectly assessed by calculating the theoretical load or with help of steam consumption according to manuals. For a number of users steam consumption is unknown and cannot be assessed. Only steam users in the bottling hall (pasteurizers and washers), the brewing vessels and hot water supply (hot liquor tanks) are involved in this calculation. For an overview of the steam and condensate system, see appendix C3. The energy content of saturated steam under certain circumstances can be found in appendix D3a.

Also condensate flows are quantified. Appendix C3 shows which users do and which do not return condensate to the boiler feed water tank.

1.1 Boiler efficiencies

The steam for all processes at the brewery is centrally produced by one of two Thompson boilers, type fired tubes with rotary cups. The second boiler is stand by. Working pressure is 80 PSIG (6.5 bar abs.). The boiler(s) are started when pressure drops below 60 psi (5 bar abs).

The efficiency of a boiler can be indirectly determined by quantifying the losses. These are flue gas losses, radiation losses, blow down losses and load losses.

- **Flue gas losses**

The flue gas losses is the heat disappearing through the stack into the air. These losses were measured by a flue gas analysis. By measuring the volume percentage of CO_2 and O_2 and the flue gas temperature at various moments the average efficiency can be determined with help of a graph as shown in appendix D3b. The result is an average flue gas loss of 14% of total oil energy input:

measurement	Boiler 1 test	Boiler 2 test
vol % O_2	7.6	8.3
vol % CO_2	10.4	11.0
flue gas temp. [°C]	182	175
ambient temp.[°C]	34	34
% flue gas losses	14-15	13-14

- **Radiation losses**

Radiation losses are losses caused by radiation of heat by the boiler. They can be assessed with the help of the graph in appendix D3c. By interpreting yearly oil consumption, a preassess of the yearly steam production and the design steam production capacity, it can be stated that average load is about 40%. So radiation losses are assessed to be 3.5%. Together with the stand by boiler the total radiation losses are assessed to be 4%.

- **Blow down losses**

Impurities in the feed water of the boiler tend to accumulate in the boiler drum. To keep these impurities within acceptable limits, an amount of water has to be removed now and then from the drum. This is called blow down.

Blow down losses are quite small and according to [Witte, p212] they are less than 1%. But at the brewery the losses must be higher. Blow down is done three times a day - which is more than average - to reduce scale forming, since little water treatment exists. Every discharge takes about a minute. With help of the graph in appendix D3d and the following data the percentage of blow down losses can be calculated:
boiler pressure: 80 PSIG (6.5 bar abs.);
blow down time: three times per day for one minute;
blow down pipe size: 3 inch;
graph ⇒ blow down flow rate: 10 kg/s;
daily blow down: 3 * 60 * 10 = 1.8 tonnes;
average steam consumption per day: 120 tonnes.

Blow down losses: 1.5%.

- **Load losses**

Load losses occur due to changes in load and losses during start ups during operation and after the weekend. The losses are assessed to be 10%. Though this loss percentage is given by literature [IRS, p8] , it is a very arbitrary number.

- **Loss and efficiency overview**

Underneath is an overview of the average boiler performance and efficiency:

Loss	[%]
Flue gas	14
Radiation	4
Blow down	1.5
Load	10
Total loss	30
Efficiency	70

Table D1.1 Boiler losses and efficiency

1.2 Total oil and steam consumption

Total steam consumption can be calculated with help of the following formula:

$\eta_b\ C_f\ m_f + h_{fw}\ m_{fw} = h_s\ m_s$ [MJ] with

m_f = $q_o\ \rho_o$ [kg];
m_f = total mass of fuel oil [kg/yr];
ρ_o = specific gravity fuel oil: 0.95 kg/l;
m_s = m_{fw} = total mass of steam
= total mass of feed water [kg/yr];
q_o = total fuel oil consumption in litres: 2,789,034 l/yr;
C_f = gross caloric value of fuel oil: 43.1 MJ/kg;
η_b = boiler efficiency: 0.70;
h_s = specific enthalpy of steam (80 PSIG): 2,760 kJ/kg;
h_{fw} = sp. enthalpy of feed water (55°C): 230 kJ/kg.

With this data can be calculated, that in 1993 $3.15 * 10^7$ kg steam has been produced. The energy contents of oil (Q_f), steam (Q_s) and feed water (Q_{fw}) are:
$Q_f = C_f m_f = 11.4 * 10^{13}$ J = 31,700 MWh/yr;
$Q_s = h_s\ m_s = 8.5 * 10^{13}$ J = 24,200 MWh/yr;
$Q_{fw} = h_{fw}\ m_{fw} = 7.2 * 10^{13}$ J = 2,020 MWh/yr.

1.3 Quantified steam users

1.3.1 Brew house

To assess steam consumption in the brew house the following data about one batch of the brewing process is needed (see table below):

Table D1.2 Brew house batch data

process step	subprocess step	final temp. [°C]	mass [kg]
mash processing	mash water in	50	13,500
	malt in		+ 3,900
	heating up mash 1st step	67	17,400
	heating up mash 2nd step	78	17,400
	sparging water in for lautering	80	+16,000
	spent grains/ water to drain		- 8,100
	result after lautering	70	25,300
wort processing	heating up wort	100	25,300
	boiling (6-7% evaporation)	100	24,600[1]

[1] The brew quantity is not 6-7% less then before boiling because of addition of extra sugar and hops during boiling.

1.3.1.1 Hot water system as steam consumer

Hot water in the brewing process is needed for mash water (50°C) during the mashing process and for sparging (80°C) water during mash lautering (grain removal). Furthermore, hot water is needed for cleaning brew vessels. Two tanks are available for these purposes. One tank, Hot Water Tank 1 (HLT 1), contains water for sparging and Hot Water tank 2 (HLT2) contains water for the mashing process.

HLT1 is filled with 55°C water which is heated up during wort cooling (energy recovery system). This water has to be heated up to 80°C, which is required for sparging. This is done with steam. HLT2 is filled with 30°C water, supplied by the brew water tank on the brew house roof. This water also has to be heated up by steam to 50°C and is needed for the mashing process. Cleaning water for the brew vessels consists of mash water and therefore is supplied by HLT2.

Most of the time water is heated up to temperatures which are higher then 50°C and 80°C. This water is mixed with cold brew water to get the required 50°C and 80°C. Because less hot water is needed in that situation the total energy need is about the same.

By determining the energy need per beer batch (235 hl), the yearly energy need can be calculated by multiplying the batch consumption by the number of brews per year. The needed warm brew water per batch is as follows:

from HLT1: 16,000 kg water of 80°C for sparging;
from HLT2: 13,500 kg water of 50°C for the mashing process. See table D1.2..

Energy need to prepare this water can be calculated.

- **Minimum energy need per year**

sparging water:

$Q_{sp} = n\, c_p\, q_{sp}\, (T_1 - T_2)$ with (1)

Q_{sp} = needed energy for sparging water [GJ/yr];
n = number of batches per year: 1342;
c_p = specific heat of water: 4.2 kJ/kg°C;
q_{sp} = quantity of needed sparging water: 16,000 kg/batch;
$T_1 - T_2$ = difference between incoming and final sparging water temperature : 80 - 55 = 25°C.
Result:
Q_{sp} = 2,250 GJ/yr = 626 MWh/yr.

The energy need for mash water heating (Q_m) can be calculated in a similar way. Cleaning water is supplied by the mash water tank (HLT2). Per week about 400 hl of cleaning water is used. This water can be seen as extra yearly batches. So for the mashing process an extra 90 batches (235 hl each) per year has to be added. The result is :

Q_m = 1,620 GJ/yr = 451 MWh/yr.

- **Steam consumption and condensate release per year**

The needed steam per year contains more energy than the minimum needed energy. Only the latent heat of steam is exchanged with the user. The latent heat is the energy released when steam turns into condensate. Besides, losses occur caused by steam transport losses, start up losses, air in steam and conversion losses. When this is translated into a formula:

$$Q_m = \eta \frac{h_l}{h_s} Q_{sm} \quad \text{with} \qquad (2)$$

Q_m = net needed energy for mash water heating: 3,000 GJ/yr;
η = efficiency = 0.7 [-], caused by steam transport losses, start up losses, air in steam and conversion losses;
Qsm = energy in steam for heating mash water [GJ/yr];
h_l = specific latent heat of steam (4.5 bar): 2,120 kJ/kg;
h_s = total specific heat of steam (4.5 bar): 2,740 kJ/kg.

Calculations show that Q_{sm} = 3,000 GJ/yr = 833 MWh.

Also the condensate flows have to be considered. The mass of condensate removed from the user equals the mass supply of steam. However, when condensate leaves, its pressure drops from steam pressure to the pressure of the surroundings. Because of this pressure drop a part of the condensate evaporates (flash steam). The mass evaporation fraction p is[1]:

$$p = \frac{h_{f1} - h_{f2}}{h_{fg2}} \quad \text{with} \qquad (3)$$

h_{f1} = enthalpy of condensate at high pressure side [kJ/kg];
h_{f2} = enthalpy of condensate at low pressure side [kJ/kg];
h_{fg2} = enthalpy of vaporization at low pressure side [kJ/kg].

With a high and low pressure of 4.5 and 1 bar the fraction p will be 0.09.

The energy condensate flow per year from the mash water heating system can be quantified with help of the following formulas:

$$Q_{sm} = m_{sm} h_s; \qquad (4)$$
$$Q_{cm} = m_{cm} h_c = 0{,}91\, m_s h_c \quad \text{with} \qquad (5)$$

m_{sm} = mass of steam for heating mash water [tonnes/yr];
Q_{cm} = energy in condensate [GJ/yr];
m_{cm} = mass of condensate which does not evaporate [tonnes/yr];
h_c = specific enthalpy of condensate (70°C): 294 kJ/kg;
0,91 = fraction of condensate mass which does not evaporate [-].

With the previously calculated Q_{sm} of 3,000 GJ/yr the mass flow for steam and condensate and the energy flow of condensate per year will be:
m_{sm} = 1,094 tonnes/yr;
m_{cm} = 996 tonnes/yr;
Q_{cm} = 293 GJ/yr = 81 MWh/yr.

---

[1] Source: [ASHRAE2, p12.2]

For the sparging water heating a similar calculation has to be done. Extra needed data:

flash steam fraction: 0.09;
enthalpy of condensate (90°C) = 378 kJ/kg.

Results:
mass of steam m_{ssp} = 1,520 tonnes/yr;
energy of steam Q_{ssp} = 4,160 GJ/yr = 1,160 MWh/yr;
mass of condensate m_{csp} = 1,380 tonnes/yr;
energy of condensate Q_{cm} = 523 GJ/yr = 145 MWh/yr.

1.3.1.2 Mash heating, wort heating and wort boiling

In the brew house energy in the form of steam is needed for increasing mash temperature and for heating and boiling of wort. Table D1.2 gives an overview of some needed process variables. The specific heats of mash and wort[1] are $c_m = 3.61$ kJ/kg°C and $c_w = 3.95$ kJ/kg°C respectively. Mash is heated from 50°C up to 78°C in two steps and wort is heated from 70°C up to 100°C. Condensate temperatures are 100°C.

Calculations for energy need for heating up mash and wort are done in the same way as shown in the section 1.3.1.1 of this appendix, using formulas (1) up to (5). This results in the following mass and energy flows:

Mash heating:
minimum needed energy = 2,360 GJ/yr = 626 MWh/yr;
mass of steam = 1,590 tonnes/yr;
energy of steam = 4,360 GJ/yr = 1,210 MWh/yr;
mass of condensate = 724 tonnes/yr;
energy of condensate = 304 GJ/yr = 84 MWh/yr.

Wort heating:
minimum needed energy = 4,020 GJ/yr = 1,120 MWh/yr;
mass of steam = 2,710 tonnes/yr;
energy of steam = 7,430 GJ/yr = 2,060 MWh/yr;
mass of condensate = 2,470 tonnes/yr;
energy of condensate = 1,040 GJ/yr = 288 MWh/yr.

The remark has to be made that one of the two mash vessels does not return condensate, so that condensate return for mash heating is half as much as should be expected.

Furthermore, energy is needed for 7% evaporation of wort. The energy needed for the boiling of the wort is calculated according the formula:

$$Q_{wb} = n\, h_{wa}\, m_{wo} \quad \text{with} \qquad (6)$$

Q_{wb} = needed energy for wort boiling [GJ/yr];
n = number of batches per year: 1,342;
h_{wa} = specific evaporation heat for water = 2,260 kJ/kg;
m_{wo} = mass of evaporated wort (7%) = 1,771 kg/batch.

Result: Q_{wb} = 5,370 GJ/yr = 1,490 MWh/yr.

---

[1] Source: [ASHRAE4, p23.2]

Mass and energy contents of steam and condensate (100°C) are:
mass of steam = 3,620 tonnes/yr;
energy of steam = 9,920 GJ/yr = 2,760 MWh/yr;
mass of condensate = 3,290 tonnes/yr;
energy of condensate = 1,380 GJ/yr = 384 MWh/yr.

1.3.2 The bottling halls

For the bottling lines the best way to assess the steam consumption was by using steam consumption according to the manuals. The steam consumers in the bottling hall are three bottle washers and three pasteurizers. The bottling process is not a batch process, so that steam consumption has to be calculated per hour. This number has to be multiplied with the total operating hours per year. This was assessed by subtracting part of down time from the regular working hours. In 1993 two out of three lines were nominally running 16 hours a day. From this 50% of the down time is subtracted, because it is assumed that in 50% of down time the equipment was really switched off. The result is an average steam demand time of 2000 hours per line per year.

Because steam consumption for the old line is unknown it is assumed that the steam consumption per hour for this line is the same as for the new lines.

- **Minimum energy need per year**

According to the manuals of the two new lines the energy consumption for washers and pasteurizers are:

- steam consumption washers: 580 kg/hr (3.5 bar abs) at continuous working conditions;
- thermal energy consumption pasteurizers: 1,863 MJ/hr.

The net steam consumption for the washers of 580 kg/hr at 3.5 bar absolute means that the minimum energy need per hour equals 1,247 MJ/hr (only latent heat of steam is exchanged).

In the writer's opinion the expression 'thermal energy consumption' for the pasteurizers means that in this energy amount condensate energy is not included, so that minimum energy need per hour equals thermal energy consumption per hour.

Total minimum energy need per year for washers and pasteurizers is obtained by multiplying with the average number of steam demand hours (2000) and the number of washers and pasteurizers (three). The result is:
washers: Q_w = 7,480 GJ/yr = 2,080 MWh/yr;
pasteurizers: Q_p = 11,180 GJ/yr = 3,110 MWh/yr.

- **Steam consumption and condensate release per year**

The formulas (2) up to (5) in section 1.3.1.1 of this appendix are used again. The same efficiency of 0.7 is used. In the bottling hall steam pressure is about 3.5 bar, so that the fraction of condensate evaporation (flash steam) according to formula (3) is 0.07. For the pasteurizers an average condensate temperature of about 70°C was measured, while the condensate of the washers left at a temperature of 90°C.

The calculated values for washers are:
mass of steam = 4,970 tonnes/yr;
energy of steam = 13,570 GJ/yr = 3,770 MWh/yr;
mass of condensate = 4,620 tonnes/yr;
energy of condensate = 1,880 GJ/yr = 522 MWh/yr.

for pasteurizers:
mass of steam = 7,430 tonnes/yr;
energy of steam = 20,280 GJ/yr = 5,630 MWh/yr;
mass of condensate = 4,610 tonnes/yr;
energy of condensate = 2,180 GJ/yr = 607 MWh/yr.

1.4 Balances of steam and condensate

The former sections can be used to make the energy and mass balances. See table D1.3 and table D3.1.

Table D1.3 Steam consumption per user

process	steam consumer	mass of steam [tonnes]	steam consumption [MWh]	steam consumption [%]	steam consumption [%]
hot water system	mash water heating	1,090	833	3	8
	sparging water heating	1,520	1,160	5	
mash processing	mash heating	1,590	1,210	5	5
wort processing	wort heating	2,710	2,060	9	20
	wort boiling	3,620	2,750	11	
bottling	washers	4,970	3,770	16	40
	pasteurizers	7,430	5,630	23	
	other users/unknown	8,570	6,780	28	28
	total steam consumption	31,500	24,200	100	100

The group 'other users/unknown' seems to be rather large. The reason for this can be that

- Efficiencies of the calculated energy consumption might be lower.
- Efficiency of the boilers is lower than estimated.
- Other made assumption or measurements are not valid.
- The other user group is really this large.
- The steam consumption in the bottling hall is much higher. Calculated consumptions were based on data from the manuals. However, measurements showed that water consumption for the pasteurizers was about 6.3 times as much as mentioned in the manuals, implying a higher steam consumption.

According to the opinion of the writer the last reason is probably one of the main causes. Nevertheless, the calculations in the next paragraph show that for this calculated situation the mass and energy balances for condensate do match.

Table D1.4 gives an overview of mass condensate flows. In appendix C3 can be seen that all condensate returners are involved in the former analysis. Condensate of one pasteurizer (old) and one mash vessel (old) are not returned, so these condensate flows are excluded in this balance. Mass loss because of blow down can be neglected.

Appendix D2a gives a complete overview of a combined mass and energy balance of the steam and condensate system.

Table D1.4 Condensate production per user

process	source of condensate	mass of condensate [tonnes]	mass of condensate [%]	mass of condensate [%]
hot water system	mash water heating sparging water heating	996 1,380	3 4	7
mash processing	mash heating	724	2	2
wort processing	wort heating wort boiling	2,470 3,290	8 11	18
bottling	washers pasteurizers	4,620 4,600	15 15	30
	not returned condensate	13,410		43
	total condensate production	31,500		100

2 Energy/mass balance for the hot water system

The hot water system provides water of 50°C and 80°C for the brewing process. During mash preparation hot water of 50°C and during lautering sparging water of 80°C is needed. Besides small quantities of both types of water are needed for cleaning.

The energy and mass balance has been already partly dealt with in the steam and condensate system, since the hot water system is a steam consumer. Not all the energy for hot water production is delivered by steam. Partly hot water is obtained by heat exchange of cold water with hot wort (heat recovery). This hot water is leaded back only to the sparging water tank.

For understanding the situation a qualitative overview is made

- Mash water (50°C) is obtained by heating up incoming water (30°C) with steam.
- Sparging water (80°C) is obtained by
    - heat exchange of down cooling wort with incoming water (30°C). The result is water with a temperature of 65°C. Due to losses during storage and transport the temperature of this water decreases to 55°C.
    - heating up 55°C water to 80°C with steam.

Measurements showed that about 27.8 m^3 water was used for cooling of each batch of wort. Yearly this means a quantity of 37300 m^3. In the section about energy balances for the steam and condensate it was stated that only 16,000 litres of water for sparging was needed per batch, which means a yearly need of 21,470 m^3. This is much less than the obtained water amount from wort heat exchange. Some of this water is used for cleaning but most of this water is drained.

Appendix D2b gives an overview of the energy and mass balance for the hot water system.

3 Energy balance for the electricity system

3.1 Total electricity consumption

In 1993 8,600,000 kWh has been consumed in total. This is measured on the high voltage side of the electricity system . The electricity is transformed from 11 kV to about 415 V with five separate transformers. Two transformers have a capacity of 1,000 kVA and the for other three the capacity is 800 kVA. The first two transformers were installed in 1969 and have a full load efficiency of 95%. The last three were installed in 1991 and their efficiency is unknown. Their efficiency is probably higher than 95%, because with the present technological know how full load efficiencies are up to 99%. The actual average load factor of the transformers at TBL is less than 0.3. According to [Austen, p114,115] transformer losses increase with another 2-3% when the load factor is 0.3 in stead of 1 (full load). Therefore the overall efficiency is assessed to be 6%. So total losses are 6% of 8,600,000 kWh, which is 520,000 kWh. The consumption of the final users is 8,080,000 kWh.

3.2 The users

It was only possible to measure electricity consumption for the ammonia compressors in the refrigeration plant, the water pump house and the air compressors. The rest was assessed with help of a total list of equipment and their rated power consumption and a record of currents for the different user groups.

Appendix D2c gives an assessed overview of the electric energy consumption of the user groups. The electric energy consumption per year is obtained by multiplying the measured or rated power by the utilization factor and operating hours per year. In case the utilization factors are multiplied by the measured power consumption (and operating hours), the factor is less then 1.0, because the power was measured during the most busy time of the operating hours. When the utilization factors are multiplied by the rated power consumption, the factor is far less then 1.0, because:

- average actual power consumption is lower then rated power consumption;
- equipment is not working continuously during operating hours.

Appendix D2c shows that the refrigeration system is by far the biggest consumer, namely about 67% of total electric energy.

4 Energy balance for the refrigeration system

Since the refrigeration system consumes about 67% of total electric energy, it is useful to further analyze this system. Unfortunately it was not possible to measure primary and secondary refrigerant flows. Therefore an approach is used in which only energy is considered and not real refrigerant flows in terms of tons per hour.

First the energy quantity which has to be withdrawn from each load is assessed. This is called the load assessment. Thereafter the electricity consumption for each load is calculated. This load consumption consists of two parts:

- Theoretical part of electricity consumption of the primary refrigeration system consumed by the specific load. This electricity consumption is calculated by dividing the total electricity consumption of the primary refrigeration system over the various loads according to the size of these loads. It is assumed that secondary refrigerant transport losses are the same for each load.
- Electricity consumption of the pumps which distribute secondary and tertiary refrigerant (spirit).

Finally the electricity consumption per MWh load is calculated for each load.

4.1 Assessment of the loads

Spirit is used for

- Wort cooling during wort processing after hop separation in the whirlpool.
- Wort cooling at the fermenting stage to remove biochemical heat. This cooling is done by spirit flowing through vessel jackets.
- Green beer cooling. After fermentation beer has to be cooled down to conditioning temperatures. This is done in the same fermentation vessels by spirit flowing through vessel jackets.
- Room air cooling system. Cold air is blown in fermenting, conditioning and other rooms
- Prefilter cooling. Before beer is filtered, beer is cooled to improve the filtering and CO_2 injection.

- **Wort cooling load during wort processing**

Wort is cooled down from about 85°C to 10°C, which is the temperature needed for fermentation. This cooling is done with a plate heat exchanger, which has two parts. In the first part heat is exchanged with water. After this water cooling the wort temperature is usually about 40°C. In the second part the wort is cooled by heat exchange with chilled spirit.

Several measurements were done to obtain the energy flows during wort cooling per batch. The average results are displayed in the table D1.5.

Since efficiency of a plate heat exchanger is close to 100%, a balance can be easily set up: wort energy decrease in second part = spirit energy increase. Wort energy decrease can be calculated. Extra needed data besides table D1.5:

ρ_{wort} = 1,050 kg/m^3;
c_{wort} = 3.80 kJ/kg°C.

Q = $V \rho c \Delta T$ [GJ/batch] with
Q = energy [GJ/batch];
V = volume [m^3/batch];
ρ = density [kg/m^3];
c = specific heat [kJ/kg];
ΔT = temperature difference [°C].

Table D1.5 average measurements for wort cooling with spirit

Variable	quantity
temperature of wort before spirit cooling [°C]	40
temperature of wort after spirit cooling [°C]	10
wort quantity [m^3/batch]	23.0

With this data the following energy balance for wort cooling can be made:

$\Delta Q_{wort} = \Delta Q_{refrig.}$ = 2.8 GJ/batch.

The yearly load is found by multiplying the spirit energy consumption per batch by the number of batches per year, which is 1,342:

Q_{L1} = 3,700 GJ/yr = 1,020 MWh/yr.

- **Wort cooling load during fermentation**

This load is the least accurate one, because the load consist of the heat released by the biochemical reaction, which occurs during fermentation:

Sugars + yeast --> CO_2 + alcohol

It has been assessed that for each batch (235 hl) about 2,500 kg of sugars is converted and the chemical energy released as heat in the above reaction is 651 kJ/kg sugar[1]. A simple calculation shows that the total yearly load Q_{L2} = 2,200 GJ/yr = 610 MWh/yr.

- **Green beer cooling load**

After fermentation green beer is cooled down further for conditioning or lagering. This cooling occurs in the fermenting vessels. The beer temperature drops from 10°C to 3°C. Total energy need per year Q_{L3} is:

$Q_{L3} = n * c_w * (T_b - T_e)$ [GJ/yr] with

n = quantity of beer cooled down per year: $3.1 * 10^7$ kg/yr;
c_w = specific heat of wort: 4.0 kJ/kg;
T_b = temperature before cooling: 10°C;
T_e = temperature after cooling: 3°C.

This results in a yearly load Q_{L3} = 870 GJ/yr = 240 MWh/yr.

- **Room air cooling load**

The load assessments of the air cooling system is based on two measurements: a measurement by the writer and one with the people from TIRDO.

Air is recirculated from the cooled rooms to the air coolers, where air is cooled spirit. This air is blown back to the cooled rooms (See appendix C5b). Cooled rooms are all rooms with fermenting, yeast, conditioning (lagering) and bright beer vessels. Furthermore, the hop store and the filtering room and the corridor between the cold rooms are cooled.

The energy needed to cool the air can be calculated. Measured parameters were air duct sizes and incoming/outgoing air speeds, temperatures and relative moistures. The air cooling takes place all year long.

The yearly load Q_{L4} is calculated with:

$Q_{L4} = \Delta t * \Sigma \dot{m} (h_1 - h_2)$ [GJ/yr] with

Δt = seconds in a year [s];
$\dot{m}$ = air mass flow [kg/s];
h_1 = enthalpy of outgoing air with moisture and temperature as measured [kJ/kg];
h_2 = enthalpy of ingoing air with moisture and temperature as measured [kJ/kg];
Σ = an addition of all air cooled spaces.

The average results are displayed in appendix D4a. Various parameters can be derived from the psychometric chart in appendix D4b. The load of the filter room is assessed, because the air in and outlets are out of reach. Air coolers for cold room 1 and 5 and yeast room were not functioning.

The total load Q_{L4} = 18,700 GJ/yr = 5,180 MWh/yr.

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[1] Source: [ASHRAE4, p23.1-4]

- **Prefilter cooling load**

Unfiltered beer is cooled before filtering to improve the filtering and CO_2 injection. This cooling is done by a plate heat exchanger. Beer is cooled from roughly 5°C to 1°C. Total load per year can be calculated, similar as done for down cooling before conditioning. This results in a load Q_{L5} of 490 GJ/yr = 140 MWh/yr.

4.2 Load overview

Table D1.6 gives an overview of the refrigeration system. Air cooling is by far the biggest load.

Table D1.6 Refrigeration load overview

Cooling load	MWh/yr	%
Q_{L1} wort during wort processing	1,020	14
Q_{L2} wort during fermentation	610	8
Q_{L3} green beer	240	3
Q_{L4} air	5,180	72
Q_{L5} beer before filtering	140	2
Total cooling load	7,190	100

4.3 Electricity consumption of the separate cooling loads

For 1993 the total compressor electricity consumption was assessed to be 3,600 MWh (see appendix D2c).

Further electricity consumers of the primary refrigeration system with used power (80% of rated power) and yearly electricity consumption are:

	used power [kW]	yearly consumption [MWh]
4 condenser fans	9.9	84
4 condenser water pumps	3.2	27
4 evaporator refrig. pumps	47.2	402
total	60.3	514

So total primary refrigeration electricity consumption is 514 + 3,600 = 4,110 MWh.

This consumption is divided over the various loads according to their size. The third column in table D1.7 shows the results.

Table D1.7 Assessed electricity consumption per load

Cooling load description	Cooling load [MWh]	Electricity consumption of primary refrig. system [MWh]	Extra Electricity consumption of secondary/tertiary refrigerant pumps, fans, etc [MWh]	Total electricity consumption [MWh]	Electricity consumption per MWh cooling load [MWh/MWh]
Wort during wort processing	1,020	583	50	633	0.62
Wort during fermentation	610	349	333	682	1.12
Green beer	240	137	83	220	0.91
Air	5,180	2,961	1,056	4,017	0.78
Beer before filtering	140	80	25	105	0.74
total	7,190	4,110	1,565	5,660	0.78

The secondary and tertiary electricity consumption of the separate loads are:

	used power [kW]	yearly consumption [MWh]
wort cooling during wort processing:		
1 spirit pump	5.9 kW	50 MWh
wort cooling during fermentation and		333 MWh
green beer cooling		83 MWh
in spirit cooled vessels (80-20%):		
11 spirit pumps	48.8 kW	
Air cooling:		
5 spirit pumps	26.4 kW	225 MWh
14 air cooler fans	98.6 kW	840 MWh
total	124.0 kW	1,056 MWh
Prefilter cooling:		
1 spirit pump	2.9 kW	25 MWh

The results are processed in the fourth column of table D1.7. This table also gives total electricity consumption per load and per MWh of load. Air cooling uses 72% of refrigeration electricity and 48% of total brewery electricity consumption. Besides the fact that the load of air cooling is big, also extra electricity is used by the air fans. Appendix D2d gives an energy balance of the total refrigeration system

5 Energy balance for the cold air system

The cold air system and its energy balance has already been explained in the section about the refrigeration system. After all, the cooling of air is a load of the refrigeration system. So here is only referred to appendix D4a with the results of measurements and appendix D2e with an overview of the energy balance of the cold air system.

6 Mass balance for the water system

Water consumption at TBL in DSM is about 40-45 hl/hl bottled beer. This is almost ten times as much as in a western brewery. Unfortunately it was not possible to measure most of the flows. Therefore an assessment is made in an indirect way.

Appendix C6a and b give the set up of the water system. Three main flows are going from the pump house to the production process:

1) sand filtered dechlorinated water used for:
   - mashing and sparging processes in the brew house;
   - flushing to clean brew vessels after cleaning with caustic;
   - boiler feed water supply;
   - drinking water;
   - water supply for condensers of the refrigeration plant;
   - cleaning;

2) sand filtered chlorinated water in:
   - the bottling halls for:
     - bottle and crate washers;
     - cooling water for fillers;
     - pasteurizers;
     - cleaning;
   - head office;

3) sand filtered chlorinated water for general purpose in the main brewery building:
   - cooling water for the ammonia, air and CO_2 compressors;
   - brew house cleaning;
   - cold room cleaning;
   - vertical fermenter filters.

Only main flow 1 and 2 are metered. The water consumption of main flow 3 is calculated by subtracting main flow 1 and 2 from the total water consumption, recorded by NUWA (National Urban Water Authority). This gives the following distribution of water consumption in 1993 over the main flows:

flow	%	annual consumption [m^3]
flow 1	22%	315,000
flow 2	34%	490,000
flow 3	44%	630,000
total	100%	1,435,000

An attempt will be made to make a mass balance for each water flow

1) Sand filtered dechlorinated water:

a) Mashing and sparging water and cleaning water: 56,600 m^3 (see energy balance hot water system)

b) Boiler make up water: (see energy balance of steam and condensate system, appendix D2a)

57 % of 31,500 m^3 = 13,400 m^3/yr.

c) Water supply for condensers of the refrigeration plant:

[ASHRAE1 p16.19] gives an average water consumption for evaporative condensers of 0.00323 m^3/(hr*kW condensed refrigerant). For TBL this would mean a water consumption of:
0.00323 * 10,510,000 = 34,000 m^3 with
10,510,000 = yearly condensed refrigerant [kWh].

d) Drinking water:

Unknown, but certainly not excessive. Overview:

Table D1.8 Mass balance for brew water

Purpose of water flow 1	quantity [m^3/yr]
mashing/sparging/cleaning water	56,600
boilers	13,400
condensers	34,000
subtotal	104,000
drinking	unknown
total	315,000

A big gap exists between the calculated water consumption of all users and total recorded water consumption.

2) Bottling hall water

The water consumption for all consuming equipment in the bottling halls, except for the washers, was measured by L. J. Kobello, a TBL engineer.

For all users counts:
net operating hours: 2,000 hrs/yr.

a) Three pasteurizers:
Specific water consumption: 18.9 m^3/hr.

Total water consumption: 18.9 * 2000 * 3 = 113,400 m^3/yr.

b) Three fillers:
Specific consumption: 2.8 m^3/hr.

Total water consumption: 2.8 * 2,000 * 3 = 16,500 m^3/yr.

This water is used to cool down the hydraulic system. The water is not recovered, but goes directly to the drain.

c) Three crate washers:

Specific consumption: 4.7 m^3/hr.

Total water consumption: 4.7 * 2,000 * 3 = 28,200 m^3/yr.

d) Three bottle washers:

Water consumption according to the manual is 9.1 m^3/hr.

The real consumption is probably much higher, because actual water consumption of the pasteurizers was 6.3 times as much as the consumption according to the manual. When this same factor difference is used the actual washer water consumption would be
9.1 * 2,000 * 3 * 6.3 = 350,000 m^3/yr. This is not possible, because then the sum of all separate users would be higher then the total consumption. The consumption based on steam use, and water temperature difference between incoming and outgoing water flows is around 120,000 m^3.

e) cleaning:

Water consumption unknown.

Overview:

Table D1.9 Mass balance for bottling water

purpose of water	quantity [m^3/yr]
pasteurizers	113,400
fillers	16,500
crate washers	28,200
bottle washers	120,000
subtotal	278,000
cleaning	unknown
total	490,000

3) General purpose water

For this water consumption no assessments can be made at all.

Total: 630,000 m^3.

- **Conclusions**

For dechlorinated water and general purpose water in the main brewery building, no satisfying balance can be set up. Nevertheless for water consumption in the bottling halls a more or less satisfying mass balance can be set up, though a significant gap between measured water flows per consumer and total recorded water consumption still exists.

Furthermore it can be stated that for the bottling process much more water is consumed than mentioned in the manuals of the equipment.

7 Energy balance for the energy recovery systems

Two kinds of energy recovery has been distinguished in chapter 2: condensate return and wort cooling by brew water during wort processing. Implicitly these subjects have already been dealt with before in the sections about the steam and condensate system and about the hot water system. When looking at appendix D2a and D2b the recovery systems can be recognized by a feed back of condensate and hot water respectively.

8 General energy and mass balances

With the former information about the various energy subsystems (energy conversion processes and the users) an energy and mass balance can be set up for the whole production process. This is done in appendix D2f. Furthermore appendix D2g gives a complete Sankey diagram for the whole Dar Es Salaam plant.

Appendix D2: Overview of mass and energy balances

Appendix D2a: Mass and energy balance for the steam and condensate system

process	IN				OUT			
	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]
steam generation	fuel oil		2,650	31,700	steam		31,500	24,200
	feed water	55	31,500	2,020	boiler losses		2,650	9,550
steam consumption	steam		31,500	24,200	users (quantified)			9,520
					other users/losses			3,710
					ret. condensate	87	18,090	1,910
					not ret. condens/ other losses		13,410	9,060
boiler feed water preparation	ret. condensate	87	18,090	1,910	boiler feed water	55	31,500	2,020
	make up SD water	30	13,410	470	losses			360
	electricity			220	loss			220

Steam consumers overview

process	IN				OUT			
	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]
mash heating	steam		1,590	1,210	energy in user			660
					ret. condensate	100	720	80
wort heating	steam		2,680	2,040	energy in user			1,120
					ret. condensate	100	2,470	290
wort evaporation	steam		3,620	2,760	energy in user			1,490
					ret. condensate	100	3,290	380
bottle washing	steam		4,970	3,770	energy in user			2,080
					ret. condensate	90	4,620	520
pasteurizing	steam		7,430	5,630	energy in user			3,110
					ret. condensate	70	4,610	400
hot water system								
mash water heating	steam		1,094	830	energy in user			450
					ret. condensate	70	1,000	80
sparging water heating	steam		1,520	1,160	energy in user			630
					ret. condensate	90	1,380	150
not quantified users	steam		8,600	6,780	energy to users (not quantified)			3,710
					ret. condensate		0	0
					losses (not ret. cond., piping, feed water tank, flash steam)		13,410	9,060
total	steam		31,500	24,200			31,500	24,200

Remarks:

- all values are sums of the whole of 1993;
- energy of water is defined as the needed energy to heat up the water from 0°C to the actual temperature.

Appendix D2b: Mass and energy balance for the hot water system

(sub)process	IN				OUT			
	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]
mash water preparation	SD water	30	19,330	680	mash water	50	19,330	1,130
	steam			450				
sparging water preparation	SD water	30	37,300	1,310	water	65	37,300	2,830
	wort	85	32,060	2,880	wort	40	32,060	1,350
	water	65	37,300	2,830	water for sparg.	55	21,470	1,380
					cleaning water/ losses	55	15,830	1,450
	water for sparging	55	21,480	1,380	sparging water	80	21,470	2,000
	steam			630				

Appendix D2c: Energy balance for the electricity system

user	Rated power [kW]	Measured power [kW]	Utilization factor [-]	Operating hours [hrs/yr]	Electricity consump. [MWh/yr]	Electricity consump [%]	Sp. el. consump [kWh/hl]
refrigeration: ammonia compressors		422	1.0	8,600	3,600	42.2	12.1
refrigeration: other	308		0.8	8,600	2,100	24.6	7.1
steam production	135	55	0.8	5,000	220	2.6	0.7
water treatment/supply		90	0.8	5,000	360	4.2	1.2
compressed air supply		88	0.9	5,000	400	4.6	1.3
CO_2 plant	66		0.4	8,600	230	2.6	0.8
malt/mash/wort processing	120		0.2	5,000	120	1.4	0.4
fermentation/ conditioning/filtering	120		0.2	5,000	120	1.4	0.4
bottling (3 lines)	610		0.4	2,000	490	5.7	1.6
lighting	40		1.0	4,000	160	1.9	0.5
AC units	30		1.0	4,000	120	1.4	0.4
transformer losses (6%)					520	6.0	1.4
miscellaneous					120	1.4	0.7
total					8,600	100.0	28.9

Remarks:

- all values are sums of the whole of 1993;
- energy of water is defined as the needed energy to heat up the water from 0°C to the actual temperature.

Appendix D2d: Energy balance for the refrigeration system

process	IN		OUT	
	material/ carrier	energy [MWh]	material/ carrier	energy [MWh]
refrigeration	electr. compressors	3,600	spirit energy to load	-7,190
	condensers	-10,510	losses primary refrig. (30% compressor input)	1,080
			losses sec./tert. refrig.	-800
	electr. primary refrig. (excluded compressors)	510	losses	510
	electri. sec./tert. refrig.	1,550	losses	1,550

Refrigeration load overview

process	IN		OUT	
	material/ carrier	energy [MWh]	material/ carrier	energy [MWh]
wort cooling during wort processing	spirit	-1,020	energy in product	-1,020
wort cooling during fermentation	spirit	-610	energy in product	-610
green beer cooling	spirit	-240	energy in product	-240
air cooling	spirit	-5,180	energy in product	-5,180
prefilter cooling	spirit	-140	energy in product	-140
				571
total	spirit	-7,190	energy in product	-7,190

Appendix D2e: Energy balance for the cold air system

process	IN		OUT	
	material/ carrier	energy [MWh]	material/ carrier	energy [MWh]
fermentation (ferm. room 1+2)	cold air	-2,960	loss	-2,960
conditioning (cold room 1-8 and corridor)	cold air	-1,930	loss	-1,930
filtering (filter room and bright beer room)	cold air	-200	loss	-200
hop store	cold air	-90	loss	-90
total	cold air	-5,180	loss	-5,180

Remark: all values are sums of the whole of 1993;

Appendix D2f: Mass and energy balance for the production process

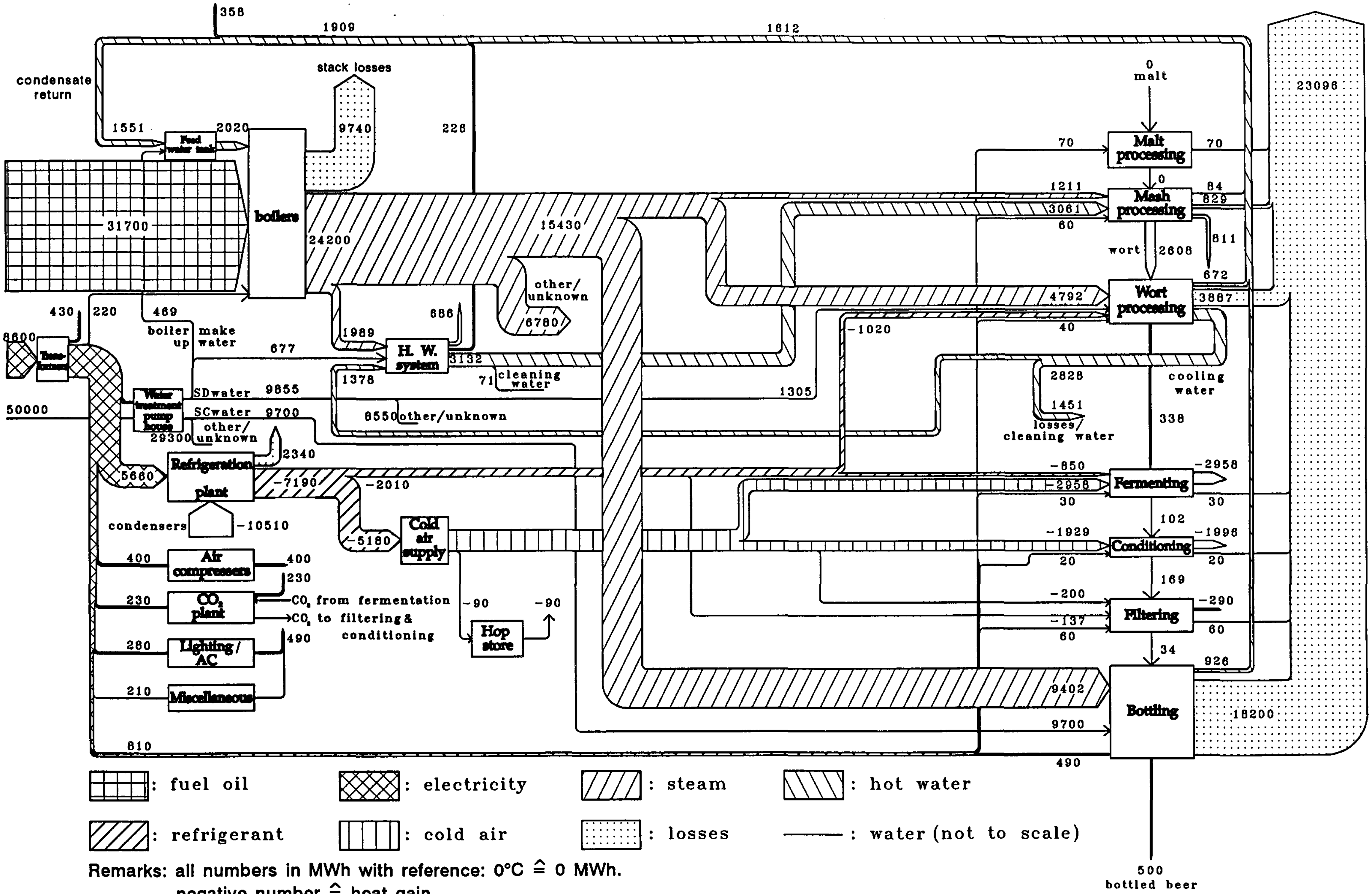
	IN				OUT			
(sub)process	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]	material/ carrier	temp [°C]	mass [tonnes]	energy [MWh]
malt processing	malt		5,230	0	malt		5,230	0
	electricity			70	loss			70
mash processing								
mash preparation	malt		5,230	0	mash	50	23,350	1,060
	mash water	50	19,330	1,130	cleaning water	50	1,210	70
mash heating	mash	50	23,350	1,060	mash	78	23,350	1,720
	steam			660				
filtering/sparging	mash	78	23,350	1,720	wort	70	33,960	2,610
	sparging wtr	80	21,470	2,000	spent grains, water & other losses		10,870	1,110
	electr mash pr.			60	loss			60
wort processing								
wort heating	wort	70	33,960	2,610	wort	100	33,960	3,730
	steam			1,120				
wort evaporation (boiling)	wort	100	33,960	3,730	wort	100	32,920	3,450
	sugar,hops		1,340	0	loss vapour		2,380	1,770
	steam			1,490				
hop separation	wort	100	32,920	3,450	wort	85	32,060	2,880
					losses		860	570
wort cooling	wort	85	32,060	2,880	wort	40	32,060	1,350
	SD water	30	37,300	1,300	water	65	37,300	2,830
	wort	40	32,060	1,350	wort	10	32,060	340
	spirit			-1,010				
	electr wort pr.			40	loss			40
fermenting								
	wort	10	32,060	340	green beer	10	30,400	340
	yeast				CO2 escape		1,660	
					biochemical heat			610
	biochemical heat			610				
	spirit			-610				
green beer cooling	green beer	10	30,400	340	green beer	3	30,400	100
	spirit			-240				
	cold air ferment.			-2,960	loss			-2,960
	electr ferment.			30	loss			30
conditioning	green beer	3	30,400	100	ripened beer	5	30,400	170
					loss			-70
	cold air condit.			-1,930	loss			-1,930
	electr conditioning			20	loss			20
filtering								
prefilt. cooling	ripened beer	5	30,400	170	ripened beer	1	30,405	30
	spirit			-140				
filtering	ripened beer	1	30,400	30	bright beer	1	30,400	30
	cold air filtering			-200	loss			-200
	electr. filtering			60	loss			60

bottling								
bottle washing	water	35	120,000	4,900	drained wtr	50	120,000	7,000
	steam			2,100				
crate washing	water	35	28,200	1,150	drained wtr	35	28,200	1,150
filling	beer	1	30,400	40	bottled beer	?	30,400	?
	cooling water	35	16,500	670	drained wtr		16,500	
pasteurizing	beer		30,400	?	past. beer		30,400	?
	water	35	113,400	4,630	drained wtr	55	113,400	7,940
	steam			5,180				
	electr. bottling			490	loss			490

Remarks:

- All values are sums of the whole of 1993;
- Energy of water is defined as the needed energy to heat up the water from 0°C to the actual temperature;
- Here only the values of latent heat exchange of steam are used. For gross steam consumption, see this type of diagram for the steam and condensate system.
- Spirit and air flows are circulating flows. The negative energy needs mean that the overall result of this circulation is negative (ingoing energy flow of circulation is smaller than the returning flows).
- Also compressed air is used in the production process, e.g. for the filtering during mash processing and the washers. Since the compressed air energy flows are unknown they are not included in this table.

Appendix D2g: Sankey diagram for the total energy system



Remarks: all numbers in MWh with reference: 0°C ≙ 0 MWh.
negative number ≙ heat gain.

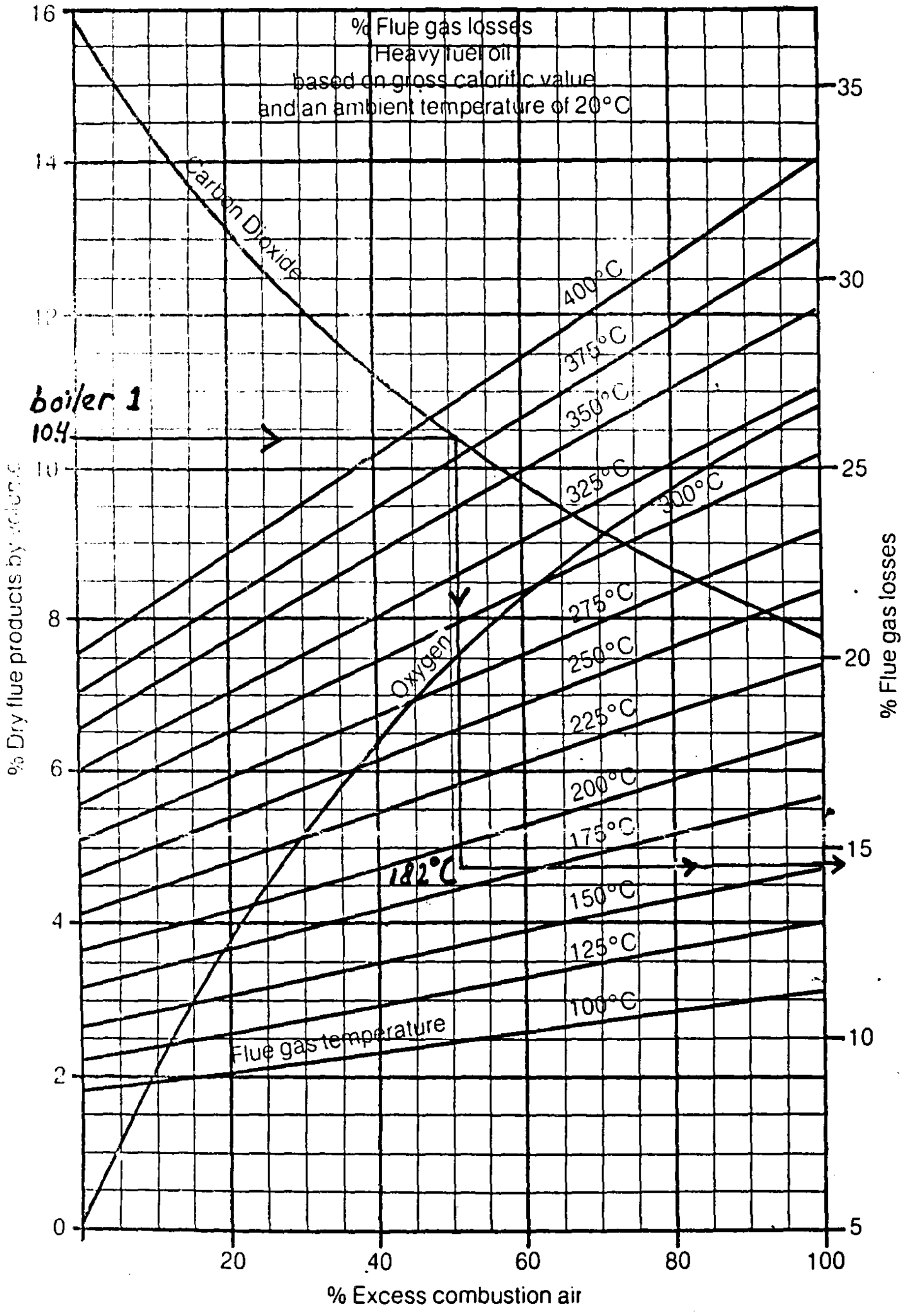
Appendix D3: Energy related tables and graphs

Appendix D3a: Saturated steam table

	Absolute	Specific Volume, m^3/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K			
Temp °C	Pressure kPa p	Sat. Solid v_l	Evap. v_{lg}	Sat. Vapor v_g	h_l	Evap. h_{lg}	Sat. Vapor h_g	Sat. Solid s_l	Evap. s_{lg}	Sat. Vapor s_g	Temp °C
96	87.771	0.001040	1.9127	1.9138	402.29	2266.80	2669.09	1.2618	6.1404	7.4022	96
97	91.033	0.001041	1.8485	1.8496	406.51	2264.18	2670.69	1.2732	6.1167	7.3899	97
98	94.394	0.001042	1.7869	1.7879	410.72	2261.55	2672.28	1.2845	6.0932	7.3777	98
99	97.853	0.001043	1.7277	1.7287	414.94	2258.92	2673.86	1.2959	6.0697	7.3656	99
100	101.420	0.001043	1.6708	1.6718	419.16	2256.28	2675.44	1.3072	6.0464	7.3536	100
101	105.095	0.001044	1.6160	1.6171	423.38	2253.64	2677.01	1.3185	6.0231	7.3416	101
102	108.877	0.001045	1.5634	1.5645	427.60	2250.99	2678.58	1.3297	6.0000	7.3297	102
103	112.773	0.001046	1.5128	1.5139	431.82	2248.33	2680.15	1.3410	5.9770	7.3179	103
104	116.782	0.001047	1.4642	1.4652	436.04	2245.66	2681.70	1.3521	5.9541	7.3062	104
105	120.908	0.001047	1.4173	1.4184	440.27	2242.99	2683.26	1.3633	5.9313	7.2946	105
106	125.155	0.001048	1.3723	1.3733	444.49	2240.31	2684.80	1.3745	5.9085	7.2830	106
107	129.524	0.001049	1.3289	1.3300	448.72	2237.63	2686.34	1.3856	5.8859	7.2715	107
108	134.015	0.001050	1.2872	1.2882	452.95	2234.93	2687.88	1.3967	5.8634	7.2601	108
109	138.635	0.001051	1.2470	1.2480	457.18	2232.23	2689.41	1.4078	5.8410	7.2488	109
110	143.390	0.001052	1.2082	1.2093	461.41	2229.52	2690.93	1.4188	5.8187	7.2375	110
111	148.271	0.001052	1.1709	1.1720	465.64	2226.81	2692.45	1.4298	5.7965	7.2263	111
112	153.289	0.001053	1.1350	1.1361	469.88	2224.09	2693.96	1.4408	5.7744	7.2152	112
113	158.447	0.001054	1.1004	1.1014	474.11	2221.35	2695.47	1.4518	5.7523	7.2041	113
114	163.749	0.001055	1.0670	1.0680	478.35	2218.62	2696.97	1.4628	5.7304	7.1931	114
115	169.192	0.001056	1.0348	1.0359	482.59	2215.87	2698.46	1.4737	5.7085	7.1822	115
116	174.786	0.001057	1.0038	1.0048	486.83	2213.12	2699.94	1.4846	5.6868	7.1714	116
117	180.530	0.001058	0.9738	0.9749	491.07	2210.35	2701.42	1.4954	5.6652	7.1606	117
118	186.420	0.001059	0.9450	0.9460	495.32	2207.58	2702.90	1.5063	5.6436	7.1499	118
119	192.476	0.001059	0.9171	0.9181	499.56	2204.80	2704.36	1.5171	5.6221	7.1392	119
120	198.688	0.001060	0.8902	0.8912	503.81	2202.02	2705.83	1.5279	5.6007	7.1286	120
122	211.603	0.001062	0.8392	0.8402	512.31	2196.42	2708.73	1.5494	5.5582	7.1076	122
124	225.198	0.001064	0.7916	0.7926	520.82	2190.78	2711.60	1.5709	5.5160	7.0869	124
126	239.496	0.001066	0.7472	0.7482	529.33	2185.11	2714.44	1.5922	5.4741	7.0664	126
128	254.518	0.001068	0.7057	0.7068	537.86	2179.40	2717.26	1.6135	5.4326	7.0461	128
130	270.306	0.001070	0.6670	0.6680	546.39	2173.66	2720.04	1.6347	5.3914	7.0261	130
132	286.871	0.001072	0.6308	0.6318	554.93	2167.87	2722.80	1.6558	5.3505	7.0063	132
134	304.251	0.001074	0.5968	0.5979	563.48	2162.05	2725.53	1.6768	5.3099	6.9867	134
136	322.479	0.001076	0.5651	0.5662	572.03	2156.18	2728.22	1.6977	5.2696	6.9673	136
138	341.568	0.001078	0.5354	0.5364	580.60	2150.28	2730.88	1.7185	5.2296	6.9481	138
140	361.572	0.001080	0.5074	0.5085	589.18	2144.33	2733.51	1.7393	5.1899	6.9292	140
142	382.503	0.001082	0.4813	0.4823	597.76	2138.34	2736.10	1.7599	5.1505	6.9104	142
144	404.392	0.001084	0.4567	0.4578	606.36	2132.31	2738.66	1.7805	5.1113	6.8918	144
146	427.306	0.001086	0.4336	0.4347	614.97	2126.22	2741.19	1.8011	5.0724	6.8734	146
148	451.222	0.001088	0.4119	0.4129	623.58	2120.10	2743.68	1.8215	5.0338	6.8553	148
150	476.207	0.001091	0.3914	0.3925	632.21	2113.92	2746.13	1.8419	4.9954	6.8372	150
152	502.292	0.001093	0.3722	0.3733	640.85	2107.70	2748.55	1.8622	4.9572	6.8194	152
154	529.499	0.001095	0.3541	0.3552	649.50	2101.43	2750.93	1.8824	4.9193	6.8017	154
156	557.882	0.001097	0.3370	0.3381	658.16	2095.11	2753.26	1.9025	4.8817	6.7842	156
158	587.472	0.001100	0.3209	0.3220	666.83	2088.73	2755.56	1.9226	4.8442	6.7669	158
160	618.283	0.001102	0.3058	0.3069	675.52	2082.31	2757.82	1.9427	4.8070	6.7497	160
162	650.382	0.001104	0.2914	0.2925	684.22	2075.82	2760.04	1.9626	4.7700	6.7326	162
164	683.792	0.001107	0.2779	0.2790	692.93	2069.29	2762.21	1.9825	4.7332	6.7157	164
166	718.546	0.001109	0.2651	0.2662	701.65	2062.70	2764.35	2.0023	4.6967	6.6990	166
168	754.675	0.001112	0.2530	0.2541	710.39	2056.05	2766.44	2.0221	4.6603	6.6824	168
170	792.245	0.001114	0.2415	0.2427	719.14	2049.34	2768.48	2.0418	4.6241	6.6659	170
172	831.293	0.001117	0.2307	0.2318	727.91	2042.57	2770.47	2.0614	4.5881	6.6496	172
174	871.852	0.001119	0.2204	0.2216	736.69	2035.74	2772.42	2.0810	4.5523	6.6333	174
176	913.902	0.001122	0.2107	0.2118	745.48	2028.85	2774.33	2.1005	4.5167	6.6173	176
178	957.586	0.001125	0.2015	0.2026	754.29	2021.89	2776.18	2.1200	4.4813	6.6013	178
180	1002.899	0.001127	0.1928	0.1939	763.12	2014.87	2777.99	2.1394	4.4460	6.5854	180
182	1049.859	0.001130	0.1845	0.1856	771.96	2007.78	2779.74	2.1588	4.4109	6.5696	182
184	1098.548	0.001133	0.1766	0.1777	780.82	2000.63	2781.45	2.1781	4.3759	6.5540	184
186	1149.005	0.001136	0.1691	0.1702	789.69	1993.40	2783.10	2.1973	4.3411	6.5384	186
188	1201.247	0.001139	0.1620	0.1631	798.59	1986.11	2784.69	2.2165	4.3065	6.5230	188
190	1255.367	0.001141	0.1552	0.1564	807.50	1978.74	2786.23	2.2356	4.2720	6.5076	190
192	1311.304	0.001144	0.1488	0.1500	816.42	1971.30	2787.72	2.2547	4.2376	6.4924	192
194	1369.253	0.001147	0.1427	0.1439	825.37	1963.78	2789.15	2.2738	4.2034	6.4772	194
196	1429.196	0.001150	0.1369	0.1380	834.34	1956.18	2790.52	2.2928	4.1693	6.4621	196
198	1491.103	0.001153	0.1313	0.1325	843.32	1948.51	2791.84	2.3118	4.1353	6.4470	198
200	1555.099	0.001157	0.1261	0.1272	852.33	1940.76	2793.09	2.3307	4.1014	6.4321	200

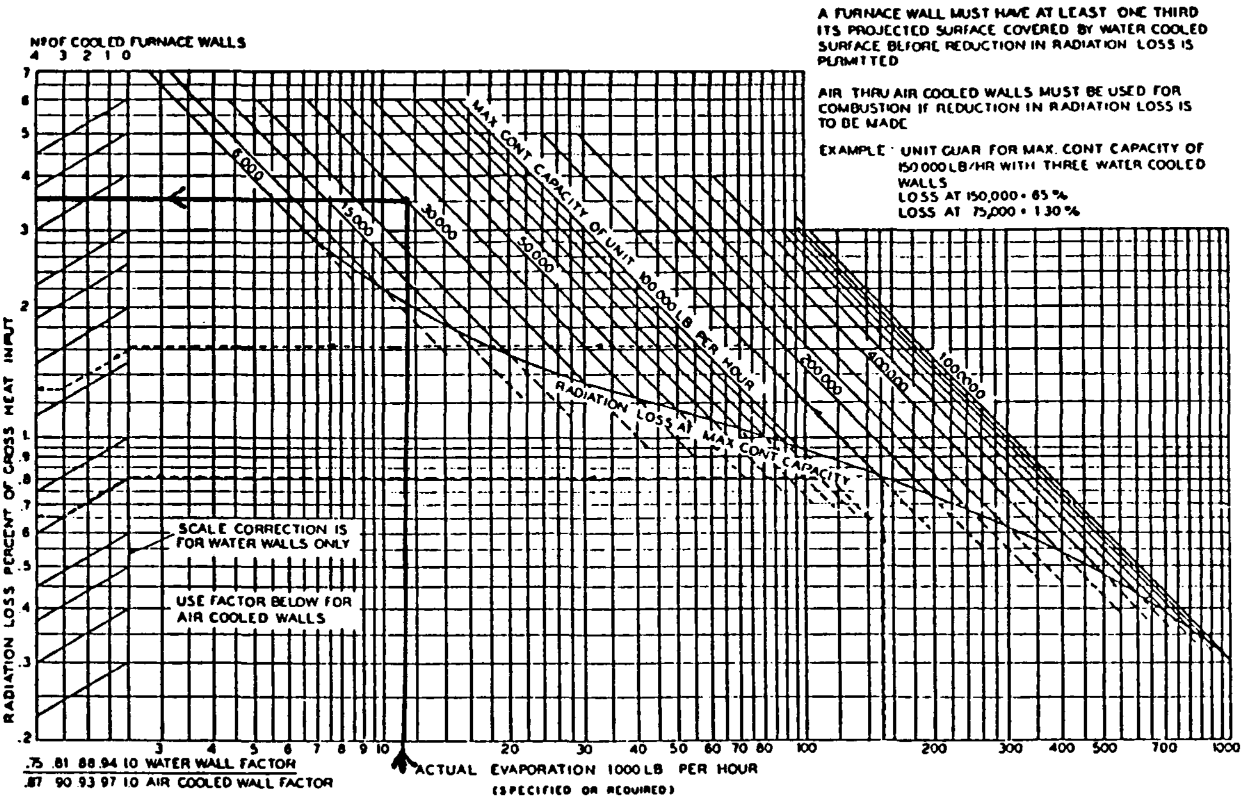
Source: [ASHRAE3, p6.7]

Appendix D3b: Percentage heat loss in boiler flue gas - heavy fuel oil



Source: unknown

Appendix D3c: Radiation losses



A FURNACE WALL MUST HAVE AT LEAST ONE THIRD ITS PROJECTED SURFACE COVERED BY WATER COOLED SURFACE BEFORE REDUCTION IN RADIATION LOSS IS PERMITTED

AIR THRU AIR COOLED WALLS MUST BE USED FOR COMBUSTION IF REDUCTION IN RADIATION LOSS IS TO BE MADE

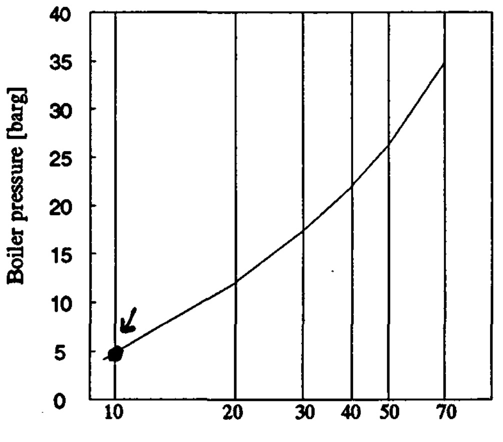
EXAMPLE · UNIT GUAR FOR MAX. CONT CAPACITY OF 150 000 LB/HR WITH THREE WATER COOLED WALLS
LOSS AT 150,000 • 65 %
LOSS AT 75,000 • 1 30 %

Source: F. William Payne, <u>Efficient Boiler Operations Sourcebook</u>, 1985

Appendix D3d: Boiler blow down rate

Blow down flow rate for a 3" blow down pipe line

as a function of boiler pressure



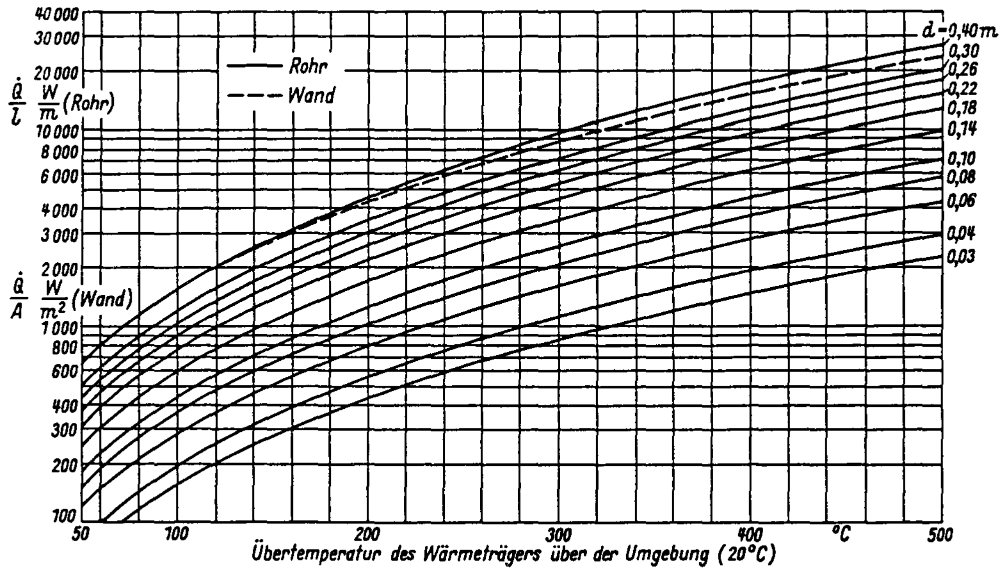
Derived from [TIRDAF, appendix 22, p5]

Appendix D3e: Steam leak losses

Pressure [bar abs]	Steam flow [kg/hr*mm^2]	
	2% humidity	saturated
1	1.08	1.07
2	1.60	1.58
3	2.11	2.09
4	2.62	2.59
5	3.12	3.09
6	3.62	3.59
7	4.13	4.09

Source: [TIRDAF,App.22]

Appendix D3f: Bare surface losses



Source: VDI Verlag, VDI Wärmeatlas, berechnungsblätter für den Wärmeübergang, 1994, page Eb 5

Appendix D4: Air related information

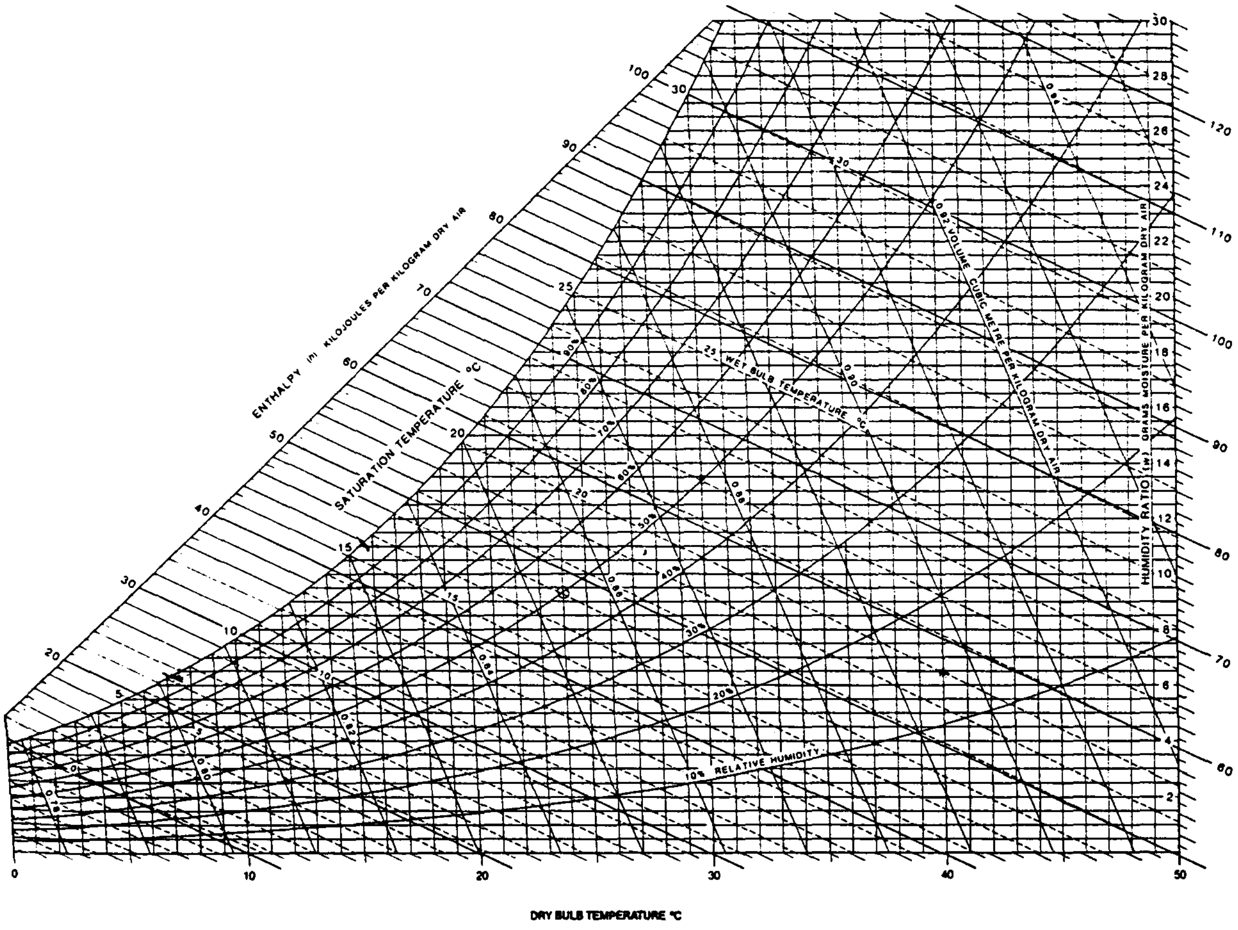
Appendix D4a: Cold air flow measurements

cooled room	temp. air out [° C]	air out enthalpy [kJ/kg]	rel. humidity [%]	temp. air in [° C]	air in enthalpy [kJ/kg]	rel. humidity [%]	air duct area [m2]	air speed [m/s]	specific weight [kg/m3]	air mass flow [kg/s]	energy flow [kJ/s]	cold room volume [m3]	spec. en. flow [kW/m3]
fermenting room 1	11.0	30.5	95	8.5	22.5	80	1.00	8.8	0.815	10.8	86.4	2510	34.4
fermenting room 2	16.0	43.5	95	10.0	27.5	90	2.63	5.1	0.833	16.1	257.6	2570	100.2
cold room 1							0.77						
cold room 2	6.9	22.5	100	4.5	16.5	90	0.71	6.3	0.800	5.6	33.5	1660	20.2
cold room 3	5.6	19	95	3.5	15	90	0.80	5.4	0.795	5.4	21.7	835	26.0
cold room 4	5.4	19	95	4.3	16	90	0.82	7.2	0.795	7.4	22.3	1310	17.0
cold room 5													
cold room 6	4.1	16	95	2.5	13	90	0.97	5.9	0.790	7.2	21.7	3260	6.7
cold room 7	4.5	17	95	2.7	13	90	0.80	5.6	0.792	5.7	22.7	2180	10.4
cold room 8	4.7	17.5	95	1.7	11.5	90	0.56	3.7	0.793	2.6	15.8	1710	9.2
hop store	6.5	19.5	85	4.2	16	90	0.59	4.0	0.797	3.0	10.4		
corridor	16.1	44	95	7.5	23	95	0.81	4.2	0.832	4.1	85.9	2240	38.3
filter room	8.3	25	95	7.3	21.5	90					15.0		
bright beer room	5.6	19	95	3.5	15	90	1.10	1.5	0.795	2.1	8.3	331	25.1
yeast room													
total											601		

Remarks:

- cold rooms are the rooms were beer is conditioning. Beer is kept in closed vessels at around 5° C by circulating cold air through the rooms were the vessels are situated
- for cold room 1 and 5 and the yeast room the air coolers were not functioning
- for the filter room the energy inflow was assessed on basis of its size

Appendix D4b: Psychometric Chart



Source: [ASHRAE3, p6.11]

Appendix D4c: Losses through walls of air cooled spaces

	area ceiling [m^2]	temp. differ. outside [°C]	losses [kW]	area front + back [m^2]	temp differ. outside [°C]	losses [kW]
fermenting room 1	550	20	2.3	140		0.8
fermenting room 2	620	20	2.6	160	20	0.9
cold room 2/3/4				260	25	1.8
cold room 6/7/8				340	25	2.4
corridor				110	25	0.8

	area left side [m^2]	temp differ. outside [°C]	losses [kW]	area right side [m^2]	temp differ. outside [°C]	losses [kW]	total wall losses [kW]	total energy inflow [kW]	% wall losses of energy inflow
fermenting room 1	230	20	1.3				6.6	78	8
fermenting room 2				230	20	1.3	7.2	258	3
cold room 2/3/4	330	25	2.3				6.2	78	8
cold room 6/7/8				480	25	3.4	8.6	60	14
corridor							1.2	86	1
total/average							29.8	560	5

Needed formula:
$Q_l = U * \Delta t * A$ [kW] with
Q_l = losses [kW];
U = specific loss [kW/m^2 °C];
Δt = temperature difference inside/outside [°C].

For walls (9" concrete wall, 6" cork insulation, 1/2" plaster):
$U = 0.21$ W/m^2°C.
For the roof (asphalt roofing felt, 3.6" concrete slab, 1/2" plaster):
$U = 0.28$ W/m^2°C.

Remarks:
- all blanks in the table means that this wall borders another cold space;
- for not mentioned cooled rooms wall sizes are unknown.

Appendix E: General data sheet

- Used exchange rate (1/1/94): 1 US$ = 510 TSh

- Production total brewed: 315,257 hl = 1342 batches of 235 hl;
  total bottled: 2,382,778 cases = 297847 hl.

- Production capacity: 7,741,440 cases/yr = 967,680 hl/yr.

- Energy consumption electricity: 8,600,000 kWh;
  oil: 2,789,000 litres;
  water: 1,315,000 m^3.

- Specific energy cost at 1/1/94 (for calculations, see next page):

Table E1 Specific energy costs

Energy carrier	Specific costs
electricity	52 TSh/kWh
prepared water	173 TSh/m^3
fuel oil	91 TSh/l
steam	12,000 TSh/MWh 9,000 TSh/tonne
steam load	17,000 TSh/MWh
spirit load	
- wort during wort processing	32,300 TSh/MWh
- wort during fermentation	58,100 TSh/MWh
- green beer	47,700 TSh/MWh
- air	47,600 TSh/MWh
- beer before filtering	46,300 TSh/MWh

- Gross operating times '93 and '94

Table E2 Gross operating times for various sections

section	'93	'94	'93	'94	'93	'94
	hrs/day		days/yr		hrs/yr	
brewing	21	24	260	360	546	8,640
refrigeration	24	24	360	360	8,640	8,640
bottling	16	24	260	260	4,160	6,240

- Pipe line costs

Mild rolled steel pipes (locally made):

2"	51,000 TSh/6m;
21/2"	45,000 TSh/6m;
3"	76,000 TSh/6m;
4"	32,500 TSh/6m.

(Source: TBL logistics department)

- Insulation costs

Glass wool insulation (imported);
$\lambda = 0.04$ W/m.
flat, 1" thick: 80,000 TSh/m^2;

For pipe lines, glass wool 1" thick, with aluminium cover, 2mm thick:

1" pipe	7,000 TSh/m;
2" pipe	14,000 TSh/m;
2½" pipe	17,500 TSh/m;
3" pipe	21,000 TSh/m;
4" pipe	28,000 TSh/m;
6" pipe	42,000 TSh/m.
(Source	glass wool prices: J. v.d. Ploeg, for Tanzan Air, DSM aluminium prices: Casements Africa Ltd, DSM)

Styropor insulation (-100° C up to 80° C, imported):
$\lambda = 0.36$ W/m;

flat, 1" thick:	2,400 TSh/m^2;
flat, 2" thick:	4,800 TSh/m^2;

for pipes, 1" thick insulation:

1" pipe	900 TSh/m;
1½" pipe	1,360 TSh/m;
2" pipe	1,710 TSh/m;
2½" pipe	2,160 TSh/m;
3" pipe	2,520 TSh/m.

(Source: Casements Africa Ltd., DSM)

Calculations of specific energy cost

Specific energy costs are needed to assess financial benefits of reduction of the consumption of a certain energy carrier. All specific costs are based on 1993 production data and 1/1/'94 water, fuel oil and electricity prices. Maintenance costs are not included here in the specific energy costs, because a consumption reduction of a certain energy carriers does not mean that maintenance costs will also decrease.

- Electricity

Since July '93 electricity prices have increased again.
Needed data based on second half of '93:

consumed electricity:	4,8 million kWh;
electricity costs:	251 million TSh.

Specific electricity costs: 52 TSh/kWh.

- Prepared water

raw water costs:	160 TSh/m^3;
electricity costs pump house:	13 TSh/m^3;
prepared water costs:	173 TSh/m^3.

- Steam

Needed data :

yearly consumed fuel oil:	2789,000 l;
fuel oil costs:	91 TSh/l ;
yearly steam generation:	24,200 MWh; 31,500 tonnes.
yearly boiler costs:	
- electricity:	11.4 million TSh;
- water	2.3 million TSh;
- boiler cement/boiler solution	10.8 million TSh;
- fuel oil:	254 million TSh;
total	278.5 million TSh.

Calculations show that specific steam costs are:

12,000 TSh/MWh or

9,000 TSh/tonne of steam.

- Steam load

The energy exchange between steam with steam load was assessed to have an efficiency of 70%. Therefore costs per MWh increase of load energy content are higher than steam costs per MWh. Results are:

17,000 TSh/MWh increase of load energy content.

- Condensate

The monetary value of condensate depends on its temperature. The assessed costs are the (net) needed steam costs to heat up condensate from the cold prepared water temperature (30° C) to the actual condensate temperature. Also the water costs have to be added.

- Refrigerant load

A distinction has to be made for separate cooling loads, because electricity consumption varies per load. In section 4.3 of appendix D1 refrigeration loads with their specific electricity consumption were assessed. These values are displayed again in the table underneath. Extra costs are the yearly make up of spirits because of leakages:

Ammonia (primary refrigerant):	4,1 million TSh;
Methylated industrial spirit (secondary/tertiary refrig.):	48,2 million TSh.

This means an extra 7.3 thousands of TSh per MWh of load. Together with the average electricity price of 52 TSh/kWh the following table can be set up:

Table E3 Specific refrigeration costs per load

Cooling load description	Cooling load [MWh]	Electricity consumption [MWh]	Electricity costs per MWh cooling load [Thousands TSh/MWh]	Total costs per MWh cooling load [Thousand TSh/MWh]
Wort during wort processing	1,020	633	32.3	39.6
Wort during fermentation	610	682	58.1	65.4
Green beer	240	220	47.7	55.0
Air	5,180	4,017	40.3	47.6
Beer before filtering	140	105	39.0	46.3
total/average	7,190	5,660	40.9	48.2

Appendix F: Calculations

Appendix F1: Calculation of energy cost reduction by capacity utilization increase

Wanted is a model for the relation between mean specific energy consumption per month and capacity utilization and the errors for this model. The calculations for figure 16 were done according to the following steps:[1]

1) Record all monthly production and energy consumption data for 1992 and 1993.
2) Find linear relation between monthly production and energy consumption:

$$\hat{y} = \beta_0 + \beta_1 * x \qquad with \qquad (1)$$

$\hat{y}$ = estimated energy consumption per month for production x;
β_0, β_1 = coefficients.

3) Find the variance of this relation, i.e. the variance of the monthly energy consumption according to the model. Use the formula:

$$\sigma^2_{\hat{y}_i} = \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{n-2} \qquad with \qquad (2)$$

$\sigma^2_{\hat{y}_i}$ = variance of monthly energy consumption estimated with the model;
y_i = energy consumption in month i and i-1 in average;
n-2 = degrees of freedom;
n = number of data.

4) Compute the variance of the mean estimated monthly energy consumption. Use the formula:

$$\sigma^2_{\hat{y}_p} = \sigma^2_{\hat{y}_i} \left(\frac{1}{n} + \frac{(x_p - \bar{x})^2}{SS_{xx}}\right) \qquad with \qquad (3)$$

$$SS_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2$$

$\bar{x}$ = mean monthly production;
x_i = production in month i;
x_p = production for which an estimation is done;
$\hat{y}_p$ = estimated mean monthly energy consumption for production x_p.

The estimated mean energy consumption per month lays within the range $\hat{y}_p \pm 2 * \sigma_{\hat{y}_p}$.

5) In figure 17 in section 5.1 the lines consist of sets of data points:

$$\left(\frac{x_p}{PC}, \frac{\hat{y}_p}{x_p}, \frac{\hat{y}_p + 2\sigma_{\hat{y}_p}}{x_p}, \frac{\hat{y}_p - 2\sigma_{\hat{y}_p}}{x_p}\right) \qquad with \qquad (4)$$

PC = production capacity.

---

[1] Formulas derived from W. Mendenhall, T. Sincich, Statistics for the engineering and computer sciences, 2nd edition, 1989, page 426 and 457

These are the points capacity utilization, estimated mean specific energy consumption per month, maximum estimated mean specific energy consumption per month and minimum estimated mean specific energy consumption per month. The actual values y_i / x_i (specific energy consumption) are indicated by little squares. Compute these data sets.

In figure 18 specific cost reduction is based on energy prices of 1/1/94. The estimated cost reduction is based on the difference of capacity utilization between the improved new capacity utilization $\frac{\hat{y}_p}{x_p}$ and the average capacity utilization in 1992 and 1993. The minimum estimated cost reduction is based on the difference between $\frac{\hat{y}_p+2\sigma_{\hat{y}_p}}{x_p}$ and the average capacity utilization in 1992 and 1993.

An example for specific electricity consumption:

1) The data:

Month	Production [cases]	Electricity consumption [kWh]	Fuel oil consumption [l]	Water consumption [m³]
1992 j	255,668	759,800	335,724	77,782
f	189,277	720,000	251,000	100,831
m	198,915	769,700	216,500	117,458
a	188,262	765,900	213,000	99,720
m	185,062	719,900	292,000	121,215
j	167,904	715,100	224,000	60,622
j	195,453	697,700	255,700	84,687
a	191,192	684,100	190,097	94,956
s	165,180	567,900	284,340	141,329
o	181,254	716,100	196,224	121,071
n	178,250	754,100	262,504	148,904
d	180,500	718,900	275,896	141,152
1993 j	176,474	645,700	174,869	81,543
f	124,635	606,800	220,249	140,720
m	152,180	694,400	135,168	135,642
a	164,655	688,000	265,132	122,142
m	181,840	721,700	217,255	152,300
j	207,270	657,600	239,976	164,261
j	222,347	754,100	185,045	123,150
a	174,094	653,500	317,763	103,289
s	214,800	932,000	244,811	114,885
o	230,661	808,200	259,857	93,646
n	241,729	779,700	239,002	97,343
d	292,084	898,600	289,907	82,964
average	194,154			
SS_{xx}	$29.004 * 10^9$			

2) and 3)

Linear regression for a relation between production in month i and production of month i and i-1 in average with help of Lotus gives the following results:

$\hat{\beta}_0$ = 467,573

$\hat{\beta}_1$ = 1.317

$\sigma_{\hat{y}_i}$ = 40,577

4) One example for a data set for figure 16 for a production capacity utilization of 50%:
Production capacity is 645,120 cases per month, so 50% capacity utilization means a production of 322,560 cases per month. With previous given model constants β_0, β_1 and formula (1) this gives an estimated electricity consumption of 892,400. The variance of the estimated mean monthly electricity consumption can be calculated with given average production, SS_{xx} and the found $\sigma_{\hat{y}_i}$. The result is $\sigma_{\hat{y}_p} = 31{,}700$.

5) Wanted is the data set (4). Production is given in cases, which must be converted to hectolitres, because the interest goes to specific consumption per hectolitre. Conversion factor is 8, because one case contains 25 bottles of half a litre. Data set (4) becomes:

capacity utilization $\frac{x_p}{PC} * 100\%$: 50%;

estimated mean specific electricity consumption per month $\frac{\hat{y}_p}{x_p} * 8 =$

892,400/ 322,560*8 = 22.1 kWh/hl beer;

estimated maximum mean specific electricity consumption per month: $\frac{\hat{y}_p + 2\sigma_{\hat{y}_p}}{x_p} =$

(892,400+2* 31,700)/ 322,560 *8 = 23.7 kWh/hl beer;

estimated minimum mean specific electricity consumption per month: $\frac{\hat{y}_p - 2\sigma_{\hat{y}_p}}{x_p}$

(892,400-2* 31,700)/ 322,560 *8 = 20.6 kWh/hl beer.

The found values match with figure 16.

Cost reduction for this example:
average specific costs based on specific consumption in 1992 and 1993 and 1/1/94 prices:
29.9 * 52 = 1560 TSh/hl with
29.9 = average specific electricity consumption in 1992 and 1993 [kWh/hl];
52 = average electricity price for 1/1/93 [TSh/kWh].

average estimated cost reduction based on improved capacity utilization of 50%:
(1,560 - 22.1 * 52)/1,560 *100% = 26%.
average minimum estimated cost reduction based on improved capacity utilization of 50%:
(1,560 - 23.7 * 52)/1,560 *100% = 21%.

These values match with figure 17.

Appendix F2: Example of cost calculation of production losses

New specific costs for a situation with less production losses is determined by first calculating the specific energy consumption in the new situation. With this new specific energy consumption the specific cost reduction is calculated. New specific energy costs are calculated with the following formula:

$$\textit{new sp. energy use} = \frac{\textit{old energy use} + \textit{extra energy use new production}}{\textit{new production}}$$

An example calculation is made for 1993 when production losses are reduced from the actual percentage of losses (16.9%) to 8%.

new specific electricity consumption =

$$\frac{8{,}599{,}300 + 0.3 * (30{,}990 - \frac{30{,}990}{53{,}340} * 25{,}220) * 29.0}{275{,}500 + (53{,}340 - 25{,}220)} = 28.8 \text{ kWh/hl sold beer} \qquad \text{with}$$

8,599,399 = Annual electricity consumption [kWh].

0.3 = Assessed fraction of the specific electricity consumption [needed for the production for one hectolitre of beer), which is consumed extra to produce bottled beer out of former lost beer [-]. This means that already 70% of energy consumed for the production of one hectolitre beer was needed to produce one hectolitre of production loss.

29.0 = Specific electricity consumption after bottling (excluding stock losses) [kWh/hl].

$(30{,}990 - \frac{30{,}990}{53{,}340} * 25{,}220)$ = production increase because of less losses [hl] with

30,990 = Production losses in old situation (excluding stock losses) [hl].

53,340 = Total losses in old situation (including stock losses) [hl].

$\frac{30{,}990}{53{,}340}$ = Fraction production losses of total losses in the old situation, which will assumed to be the same in the new situation [-].

25,220 = Total losses in new situation (including stock losses) [hl]

= 8% of total beer quantity after start of brewing (315260 hl).

275,500 = Sold beer quantity in old situation [hl].

(53,340 - 25,220) = Increase of total sold beer quantity [hl].

The result is a new specific electricity consumption of 28.8 kWh/hl while it was 31.4 kWh/hl in the old situation. Simular calculations can be done to determine specific consumption of fuel oil and water in the new situation. Extra needed data are:

annual fuel oil consumption:	2,789,000 l;
specific fuel oil consumption after bottling (excluding stock losses):	9.4 l/hl;
annual water consumption:	14,120,000 hl;
specific water consumption after bottling (excluding stock losses):	47.4 hl/hl.

The results are a reduction of specific consumption for fuel oil from 10.1 l/hl to 9.3 l/hl and for water from 51.2 hl/hl to 47.3 hl/hl.

Finally specific energy cost reduction by decrease of production losses can be calculated

carrier	specific energy costs with 17% production losses (1993) [TSh]		specific costs with 8% production losses [TSh]	
electricity	31.4 * 52 =	1,630	28.8 * 52 =	1,498
fuel oil	10.1 * 91 =	919	9.3 * 91 =	846
water	51.2 * 16 =	819	47.3 * 16 =	757
total		3,370		

The specific cost reduction = (3,370 - 3,101)/3,370 * 100% = 8.0%. This value matches with one specific value in figure 18.

Appendix F3: Cost calculation of open doors of air cooled spaces

A formula for heat infiltration of open doors can be found in [ASHRAE3, p29.3]:

$$q = 0.221 * A * (h_i - h_r)\,\rho_r\,(1 - \rho_i / \rho_r)^{0.5}(gH)^{0.5}\left[\frac{2}{1 + (\rho_r / \rho_i)^{0.33}}\right]^{1.5} \quad \textit{with}$$

q = heat gain [kW];
A = doorway area [m^2];
h_i = enthalpy of infiltration air [kJ/kg];
h_r = enthalpy of refrigerated air [kJ/kg];
ρ_i = density of infiltration air [kg/m^3];
ρ_r = density of refrigerated air [kg/m^3];
g = gravitational constant = 9.8 m/s^2;
H = doorway hight [m].

Needed data:
A = 2 m$^{2;}$
H = 2 m.
with help of the psychometric chart in appendix D4b:
h_i = 100 kJ/kg (70% relative humidity, 30°C);
h_r = 18 kJ/kg (90% relative humidity, 5°C);
ρ_i = 1.11 kg/m^3 ;
ρ_r = 1.26 kg/m^3 .

Calculations show that q = 68 kW. For an air cooling load of 68 kW around 53 kW extra electricity is needed (see appendix D1, table D1.7, page 119). This equals the power consumption of 530 light bulbs of 100 W.

Appendix F4: Calculation of influence of direct factors on specific energy costs in comparison with a western brewery

The recognized direct factors were:

- capacity utilization;
- production losses;
- climate;
- energy prices/tariffs;
- energy efficiency of the equipment;
- know how to use equipment in an energy efficient way;
- production organisation;

Only the effect of the first four factors on specific energy costs can be assessed separately. The minimum effect of the last three factors together can be assessed by adding the found energy cost savings by implementation of energy conservation measures.

The idea is to find the separate contribution of these factors for the higher specific energy costs at TBL in comparison with a western brewery. When the effect of one factor is analyzed, it is assumed that the other factors will stay the same. The characteristics of an imaginary western brewery are listed below:

Brewery XYZ:
specific electricity consumption: 10.3 kWh/hl beer output;
electricity costs: 72 TSh/kWh el., 750 TSh/hl beer output;
specific fuel oil consumption: 3.2 l/hl beer output;
fuel oil costs: 160 TSh/l oil, 520 TSh/hl beer output;
specific water consumption: 6.5 hl/hl beer output;
water costs: 45 TSh/hl wtr, 295 TSh/hl beer output;
Total of specific electricity, fuel oil and water costs: 1,565 TSh/hl beer = 3.1 US$/hl beer;
capacity utilization: 80%;
production losses: 6%;
climate: average temperature of 12°C, 70% relative humidity.

The 1993 characteristics for TBL DSM are (prices of 1/1/'94):

specific electricity consumption: 31.4 kWh/hl beer output;
electricity costs: 52 TSh/kWh el., 1,630 TSh/hl beer output;
specific fuel oil consumption: 10.1 l/hl beer output;
fuel oil costs: 91 TSh/l oil, 920 TSh/hl beer output;
specific water consumption: 51.2 hl/hl beer output;
water costs: 16 TSh/hl wtr, 820 TSh/hl beer output;
Total of specific electricity, fuel oil and water costs: 3,370 TSh/hl beer = 6.6 US$/hl beer;
capacity utilization: 30%;
production losses: 16%;
climate: average temperature of 25°C, 70% relative humidity.

Specific energy consumption and costs for brewery XYZ are based on an article in Brauwelt, nr 46 (1992), p2427-2429. The given specific energy consumptions and costs are the average of breweries in Germany in 1991 with an annual production between 100-500 hl per year. Capacity utilization and production are data from P. van Leuken, Bavaria B.V., the Netherlands. TBL pays more than twice as much energy costs per hectolitre of beer than a western brewery.

1 Influence of capacity utilization on specific energy costs

In section 5.1 a relation was found between capacity utilization and specific energy costs. According to this relation a cost reduction of 44% is possible when capacity utilization at TBL will increase from 30% to 80%.
Cost reduction in Tanzanian Shillings is:
0.44 * 3,370 = 1,480 TSh/hl with
3,370 = total of electricity, fuel oil and water costs [TSh/hl].

2 Influence of production losses

In section 5.2 a relation was found between production losses and specific energy costs. The expected energy cost reduction is 9.5% when production losses decrease from 17% to 6%. Cost reduction in Tanzanian Shillings is:
0.095 * 3,370 = 320 TSh/hl.

3 Influence of the climate on specific energy costs

The difference of energy costs is assessed when TBL is moved in unchanged state from Tanzania to e.g. the Netherlands. The following assumptions are made about supply water temperatures are made:

For Tanzania: (at TBL):	30°C
For the Netherlands:	12°C

The following aspects are considered:

- warmer incoming water, having a mainly decreasing effect on energy cost on
    - hot water production by hot water system;
    - wort cooling during wort processing;
    - water heating in the bottling halls;
    - boiler make up water;
- the influence of the weather on refrigeration (increasing cost effect).

Influence of warmer incoming water

Hot water production by hot water system

The hot water system produces 50°C mash water in hot water tank 2 and 80°C sparging water in hot water tank 1. Mash water is obtained by steam heating and sparging water up to a temperature of about 55°C is obtained by heat exchange with cooling down wort. Therefore climate has only influence on mash water heating.

Cost difference:
(30-10) * 4.2 * 19,330 /3,600 * 17,000 = 8 million TSh/yr with
(30-10) = water temperature difference Netherlands-Tanzania [°C];
4.2 = specific heat water [kJ/kg];
19,330 = needed mash water per year [tonnes/yr];
3,600 = conversion factor MJ -> MWh;
17,000 = steam costs [TSh/MWh of load].

Water for wort cooling during wort processing

Worth cooling is done in the first step with water and in the second step with spirit. The warmer cooling water in Tanzania has less cooling capacity and therefore more spirit energy is needed. Decrease of energy in water cooling equals the energy increase of spirit cooling. The extra spirit costs are:

(30-10) * 4.2 * 37,230 /3,600 * 32,300 = 28 million TSh/yr with
37,230 = needed cooling water per year [tonnes/yr];
32,300 = spirit costs [TSh/MWh of load].

Water in the bottling halls

The main users are bottle washers and pasteurizers. Water for washers and pasteurizers is steam heated. The extra costs for the washers are:

(30-10) * 4.2 * 120,000 /3,600 * 17,000 = 48 million TSh/yr with
120,000 = water consumption of all bottle washers [tonnes/yr].

For the pasteurizers the situation is more complicated. Cold water supply is situated in the last compartment of the pasteurizers, where it is used to cool down the just pasteurized beer. So colder supply water probably has not a big effect on the energy consumption of the pasteurizers. The only effect is that the beer coming out of the pasteurizer will be colder.

Boiler make up water

Costs of lower water supply temperature of the boiler water can be expressed as the costs of temperature increase by steam heating:

(30-10) * 4.2 * 13,400 /3,600 * 17,000 = 5 million TSh/yr with
13,400 = needed make up water for the boilers per year (tonnes/yr].

Influence on refrigeration

The influence of the climate on the refrigeration system has two impacts. The refrigeration load is bigger because of the climate. The main load is the air cooling load and the effect of the climate will be by far the largest on this load. Second is the effect on the heat rejection at the condensers.

Air cooling load

During the set up of energy balance for the refrigeration system (appendix D4a) it was measured that the air cooling load was 601 kW. During the evaluation of the refrigeration system in section 5.3 the assessment was made that around 5% of the air cooling load was lost due to (unavoidable) losses through walls. When the lighting in the fermenting rooms and the body heat of people is also seen as unavoidable, the total losses by outside air infiltration through open doors and holes is assessed to be 90%. So this loss is 90% of 601 kW = 541 kW. No formula or relation is known to describe air infiltration through holes in the walls. However, a formula is known for outside air infiltration through doors as used in appendix F3. The determining factor in this formula is the proportional relation between the difference of the enthalpy of inside and outside air and the loss. In formula:

q_l = $C * (h_l - h_r)$ with
q_l = loss [kW];
C = more or less a constant [kg/s] ;
h_l = enthalpy of infiltrating air [kJ/kg];
h_r = enthalpy of inside air [kJ/kg].

The difference in loss can now be calculated by

$$q_{lnl} = \frac{h_{lnl} - h_{rnl}}{h_{ltz} - h_{rtz}} * q_{ltz} \quad \text{with}$$

subscribt nl = Netherlands;
tz = Tanzania;

q_{ltz} = 541 kW;
h_{lnl} = 27.5 kJ/kg (12°C, 70%);
h_{rnl} = 15.5 kJ/kg (4°C, 90%, it is assumed that because of colder climate in the Netherlands temperature will drop to the average prescripted 4°C);
h_{ltz} = 61 kJ/kg (25°C, 70%);
h_{rtz} = 21 kJ/kg (7°C, 90%).

For the determination of the enthalpies, see appendix D4b with the psychometric chart. Calculations show that the load loss in the Netherlands would be q_{ltz} = 162 kW. The load in the Netherlands would be 601 - 540 + 162 = 223 kW.

The cost difference is:
(601 - 223) * 8,600 /1,000 * 47,600 = <u>155 million TSh</u> with
(601 - 223) = decrease of air cooling load [kW];
8,600 = operating hours per year [hr/yr];
1,000 = conversion factor kWh -> MWh;
47,600 = air cooling load costs [TSh/MWh].

Heat rejection at the condensers

The used condensers at TBL are evaporative condensers. Spirit heat is rejected by evaporating water. This water is condensed again by a forced air inflow. The heat rejection flow of spirit to water equals heat rejection of condensing water to air. For heat rejection of water to air the following formula can be set up [ASHRAE1, p16.16]:

$q_c = U_c * A (h_s - h_e)$ with
U_c = heat transfer coefficient from the water-air interface to the air stream [W/m^2];
A = area of water-air interface [m^2];
h_s = enthalpy of saturated air at the temperature of water-air interface (t_s) [kJ/kg];
h_e = enthalpy of air entering the condenser [kJ/kg].

The heat rejection flows will be compared for the Netherlands and Tanzania in the following formula:

$$\frac{q_{ctz}}{q_{cnl}} = \frac{h_{snl} - h_{enl}}{h_{stz} - h_{etz}}$$

It is assumed that t_s is the same for Tanzania as for the Netherlands and equals the condensing temperature of the spirit, which is 37°C. So $h_{snl} = h_{stz}$ = 143 kJ/kg
Other values to be filled in are:
h_{enl} = 27.5 kJ/kg (12°C, 70%);
h_{etz} = 61 kJ/kg (25°C, 70%).

Calculations give the following result: q_{ctz} / q_{cnl} = 0.71. The meaning of this outcome is that the heat rejection flow in Tanzania will be about 71% of the flow in the Netherlands because of the climate. This means that less electricity input is needed for the primary refrigeration system. When this quantity is calculated, also the fact that the air cooling load is smaller now has to be considered.

The new air cooling load is:
Q_{nl} = 5,180 - (601 - 223) * 8,600 /1,000 = 1,930 MWh with
5,180 = air cooling load as now in Tanzania [MWh].

The yearly reduction electricity consumption of primary refrigeration because of smaller air cooling load is:
W_{rnl} = 4,110 - 4,110/7,190 * (5,180 - 1,930) = 2,250 MWh with
W_{rnl} = primary refrigeration electricity consumption with smaller air cooling load [MWh];
4,110 = electricity consumption of primary refrigeration in old situation [MWh];
4,110/7,190 = electricity consumption of primary refrigeration per MWh of load [MWh/MWh] (see appendix D2c);
(5,180 - 1,930) = reduction of air cooling load [MWh].

So the cost difference because of better heat rejection at the condensers is:
0.29 * 2,250 * 1,000 * 52 = 34 million TSh with
0.29 = fraction of improved heat rejection [-];
2,250 = new electricity consumption of primary refrigeration [MWh];
52 = electricity costs [TSh/kWh].

Overview influence of climate

Here an overview is given for the influence of climate:

Cause of influence	Cost increase in Tanzania [million TSh/yr]
hot water production by hot water system	-8
water for wort cooling during wort processing	+28
water in the bottling halls	- 48
boiler make up water	-5
air cooling load	+155
heat rejection at the condensers	+ 34
Total	+156

So the effect of refrigeration is very big and is a reduced little by the fact that incoming water is warmer. The effect will be higher in practice, because e.g. the effect of uninsulated pipes and vessels in a colder climate are not considered.

In 1993 the production was 300,000 hl, so that the specific energy costs are 520 TSh/hl higher because of the climate.

4 Influence of energy price difference

The specific cost reduction is calculated when TBL would have to pay energy prices of the western brewery:
electricity price: 72 TSh/kWh electr.;
specific electricity consumption: 31.4 kWh/hl beer output;
specific electricity costs: 2,260 TSh/hl beer output;

fuel oil price: 160 TSh/l fuel oil;
specific fuel oil consumption: 10.1 l/hl beer output;
specific fuel oil costs: 1,616 TSh/hl beer output;
water price: 45 TSh/hl wtr;
specific water consumption: 47.4 hl/hl beer output;
specific water costs: 2,130 TSh/hl beer output;
Total of specific electricity, fuel oil and water costs: 6,010 TSh/hl beer.

So the cost increase for TBL would be:
6,010 - 3,370 = 2,640 TSh/hl beer output = US$ 5.2 /hl beer output.

5 Influence of improvement of energy efficiency by technology, maintenance and organisation improvement

The minimal cost possible cost decrease can be assessed by the energy conservation opportunities on these areas, as indicated in chapter 5
Total savings (see table 17, section 5.6) are 304 million TSh, which means 1000 TSh/hl beer output. In reality this number will be higher, because not all possible ECO's are treated and/or quantified.

6 Overview

The following list gives an overview of quantified causes of higher specific energy costs at TBL:

	TSh/hl	US$/hl
TBL DSM specific energy costs:	3,370	6.6
Reference specific energy costs:	1,565	3.1
Lower specific energy costs at TBL caused by:		
Lower energy prices:	-2,630	-5.2
Higher specific energy costs at TBL caused by:		
Lower capacity utilization:	+1,480	+2.9
More production losses:	+ 320	+0.6
More hot and humid climate:	+ 520	+1.0
Technical/maintenance/organizational short comings:	+1,000	+2.0

It must be realized, that various causes can not be added, because they are overlapping.