

Note

To: CREATIV

From: Stein Rune Nordtvedt (IFE), Arne Lind (IFE) og Eva Rosenberg (IFE)

Copy: Roy Stenbro (IFE)

Date: 2011-06-30

Generic model of energy consuming processes in food industry

1 Introduction

The R&D Project funded by the Research Council of Norway called KMB CREATIV – Competence project for Reduced Energy use through Advanced Technology InnoVations has five different areas of work. This note is part of Sub-Project 3: “Utilization and storage of thermal energy” and Work Package 3.2: “Concepts for surplus heat exploitation” and describes the first steps in the development of a generic model for energy savings in food industries. To illustrate the use of the model, a case study of a process line at TINE Meieriet Verdal is carried out.

The case studies of CREATIV are supposed to be generic and be of utility value for as many industries as possible. The reasons for choosing TINE Meieriet Verdal as one of the case studies of the CREATIV project were mainly:

- Water sources and water consumption at different temperatures for both heating and cooling are common of many food industries
- The potential for energy savings based on water recovery is high and widespread in the food industry
- TINE Meieriet Verdal is probably more complex than most food industries
- A generic tool for energy and water recovery of batch processes would be an important contribution to energy and water savings in food industry
- An exemplification of the possibilities of the use of low temperature waste heat in combination with heat pumps will be useful
- This is a valuable input to other parts of the CREATIV project (pilot plant etc.)

A generic tool for energy and water recovery of batch processes has been developed in the CREATIV project, based on a previous case study. The main use of this model will be in the food industry or other small to medium sized industries with batch processes and use of water. The case study of TINE Meieriet Verdal (Rosenberg, 2010) studied different possibilities of water recovering tanks with and without heat pumps. Four

alternatives were presented, with two to four water tanks and no, one or two heat pumps. The savings calculated was 15 to 27 GWh/year of a total use of 65 GWh/year.

In Chapter 2, a short description of the modeling tool used is given and the model is described in chapter 3.

2 The modelling tool – TRNSYS

2.1 Introduction

The TRaNsient SYstems Simulation Program (TRNSYS) is an energy simulation software package that has been available for 35 years. TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of a system whose behavior is dependent on the passage of time.

TRNSYS is a software package that has been commercially available since 1975. The software package consists of a graphical front-end (TRNSYS Simulation Studio) to intuitively create a simulation, an interface for the detailed TRNSYS multi-zone building (TRNBuild/Type56), a Google SketchUp plugin for creating the multi-zone building envelope (TRNSYS3D), and a tool for manually editing the TRNSYS input files and creating stand-alone TRNSYS-based applications (TRNEdit/TRNSED). TRNSYS takes a modular, "black box" component approach to developing and solving simulations: the outputs of one component are sent to the inputs of another component (transient successive substitution). TRNSYS has been used extensively but is not limited to simulate solar processes and other renewable energy, high performance buildings, and electric power generation.

2.2 Library

TRNSYS offers a broad variety of standard component, and many additional libraries are available to expand its capabilities. About one hundred models are included in the Standard TRNSYS Library. These models are organized into 14 categories (see Table 1).

Table 1: Standard Component Library Overview

Category	Name
1	Controllers Contains various general purpose controllers and thermostats.
2	Electrical Contains components that generate or store electricity and their accessories: solar photovoltaic (PV) systems, Wind Energy Conversion Systems (WECS, or wind turbines), Diesel engines, Power conversion systems, batteries.
3	Heat Exchangers Contains various types of heat exchanger and energy recovery devices.
4	HVAC Contain several auxiliary heating and cooling devices, including absorption cooling machines.
5	Hydrogen Systems Most components from the HYDROGEMS library are in this category. The HYDROGEMS library provides models to simulate Hydrogen-based systems: fuel cells, electrolyzers, hydrogen storage devices, etc.
6	Hydronics Fans, pumps, pipes, ducts and flow diverters or mixers are included here.
7	Loads and Structures Contains the multizone building model and other monozone models of increasing complexity.
8	Obsolete Models kept for backwards compatibility.
9	Output Printers and online plotters are in this category, as well as components that realize a simulation summary or further analyze simulation results.
10	Physcial Phenomena Contains utility components that model physical phenomena. It includes psychrometrics calculations and the well-known solar radiation processor. It also includes shading calculations, sky temperature and convection coefficients.
11	Solar Thermal Collectors Contains modles for different types of solar thermal collectors: flat-plate collectors, evacuated tube collectors, Concentrating Parabolic Collectors, etc
12	Thermal Storage Contains different models of storage devices: stratified or plug-flow water tanks with optional heat exchangers, rock beds, etc.
13	Utility Contains groups of utility components such as unit conversion, forcing functions, input value recall, etc. It also includes components calling external programs such as EES, Excel or Matlab, and the "Data Reader" group.
14	Weather Data Reading and Processing Contains the combined data reader and solar radiation processor that allows users to easily read standard or user-format weather files and calculate the incident solar radiation on any surface.

In addition, TESS has developed over 500 TRNSYS components. These additional libraries can be purchased and included in the TRNSYS software package. At IFE, we have installed two such TESS libraries:

- **Geothermal Heat Pump (GHP) Components:** The TESS GHP Library is not only host to extensive ground heat exchanger models (horizontal multi-layer ground heat exchanger, and the vertical heat exchanger), but also to buried single and double pipes, and various heat pump models as well.
- **HVAC Equipment Components:** With over 60 different components, the TESS HVAC Library is a far ranging group of components for modeling anything related to heating, ventilation, and air conditioning of buildings. Residential, commercial, and industrial HVAC components are all included.

In the simulation model describing TINE Meieriet Verdal, the following TRNSYS components are used:

- **Forcing functions (General):** Describes a time dependent forcing function which has a behaviour characterized by a repeated pattern.
- **Quantity integrator:** This component integrates a series of quantities over a period of time.
- **Online plotter without file:** The online graphics component is used to display selected system variables while the simulation is progressing.
- **Flow mixer (other fluids):** This instance of the flow mixer is used to model a controlled flow mixer in which two inlet liquid streams are mixed together according to an internally calculated control function so as to maintain the mixed outlet temperature at or below a user specified value.
- **Variable volume tank:** This component models a fully-mixed tank with a constant cross-sectional area that contains a variable quantity of fluid. In its simplest form, a single flow enters from a hot source and a single flow stream exits to a load. Since the incoming and outgoing flows need not be equal, the level of fluid in the tank can vary. The level is allowed to vary between user specified high and low level limits. If the lower limit is reached, the load flow necessary to maintain this level is output rather than the desired load flow. If the volume of fluid exceeds the upper limit, then the excess flow necessary to keep the tank at the upper limit is set as an output.
- **Water-cooled chiller (TESS):** This component models a vapour compression style water cooled chiller. It relies on catalogue data provided as external text files to determine the chiller performance.
- **Online plotter with file – no units:** The online graphics component is used to display selected system variables while the simulation is progressing. The selected variables will be displayed in a separate plot window on the screen. In this instance of the online plotter, data sent to the online plotter is automatically printed, once per time step to a user defined external file.
- **Heat exchanger (Counter flow):** A zero capacitance sensible heat exchanger is modelled in various configurations. In this instance, a counter flow heat exchanger is modelled. Given the hot and cold side inlet temperatures and flow rates, the effectiveness is calculated for a given fixed value of the overall heat transfer coefficient (product of U and A).
- **Heat exchanger, fluid-to-fluid (TESS-HVAC):** Along with its sister types, this component uses a constant effectiveness / C_{min} approach to predict heat exchanger performance. The heat exchanger is designed to automatically determine the fraction of cold-side fluid that should be bypassed around the heat

exchanger in order to maintain the hot-side outlet temperature at or above its time dependent set point.

- **Water – water heat pump (TESS-HVAC):** This component models a single-stage vapour compression heat pump. The heat pump conditions one liquid stream by rejecting energy to (cooling mode) or absorbing energy from (heating mode) a second. This model is based on user-supplied data files containing catalogue data for the capacity and power draw, based on the entering load and source temperatures.
- **Flow diverter (other fluids):** This instance of the flow diverter model models a flow diverter in which a single inlet liquid stream is split according to a user specified valve setting into two liquid outlet streams.
- **Pumps (variable speed):** This component models a variable speed pump that is able to maintain any outlet mass flow rate between zero and a rated value. The mass flow rate of the pump varies linearly with control signal setting. Pump power draw, however, is modelled using a polynomial.
- **Iterative feedback controller:** The iterative feedback controller calculates the control signal (u) required to maintain the controlled variable (y) at the set point (ySet). It uses TRNSYS iterations to provide accurate set point tracking.
- **Equations:** A very useful feature in TRNSYS is the ability to define equations within the input file which are not in a component. These equations can be functions of outputs of other components, numerical values, or previously defined equations. These equations can then be used as inputs to other components, or as parameters, initial values of inputs, or derivatives if the equations are time independent.

2.3 Model generation

With the TRNSYS graphical interface (see figure 1), the Simulation Studio, the user can connect the outputs from one component to the inputs of another. Such a connection is a “pipeline” of output-input connections between two components. The direction of information flow is from the first model to the second model (outputs of first model ==> inputs of second model). An important step in the creation of a model in the Simulation Studio is the specification of the required variables for each component model. The specific variable (input, output, parameter, and derivative) window can be accessed in the assembly panel by double-clicking the desired model icon. The parameters, inputs, outputs and derivatives are all available in a single window using a tabbed view. The user is required to specify all the parameters, the initial values for all the inputs, and any derivatives that may be present in the model. The output window is just for informational purposes. Failure to provide any of this information to the component model will result in default information being used for the component.

The Simulation Studio saves the project information in a Trnsys Project File (*.tpf). When you run a simulation, the Studio also creates a TRNSYS input file (text file that contains all the information on the simulation but no graphical information). The simulation Studio also includes an output manager from where you control which variables are integrated, printed and/or plotted, and a log/error manager that allows you to study in detail what happened during a simulation.

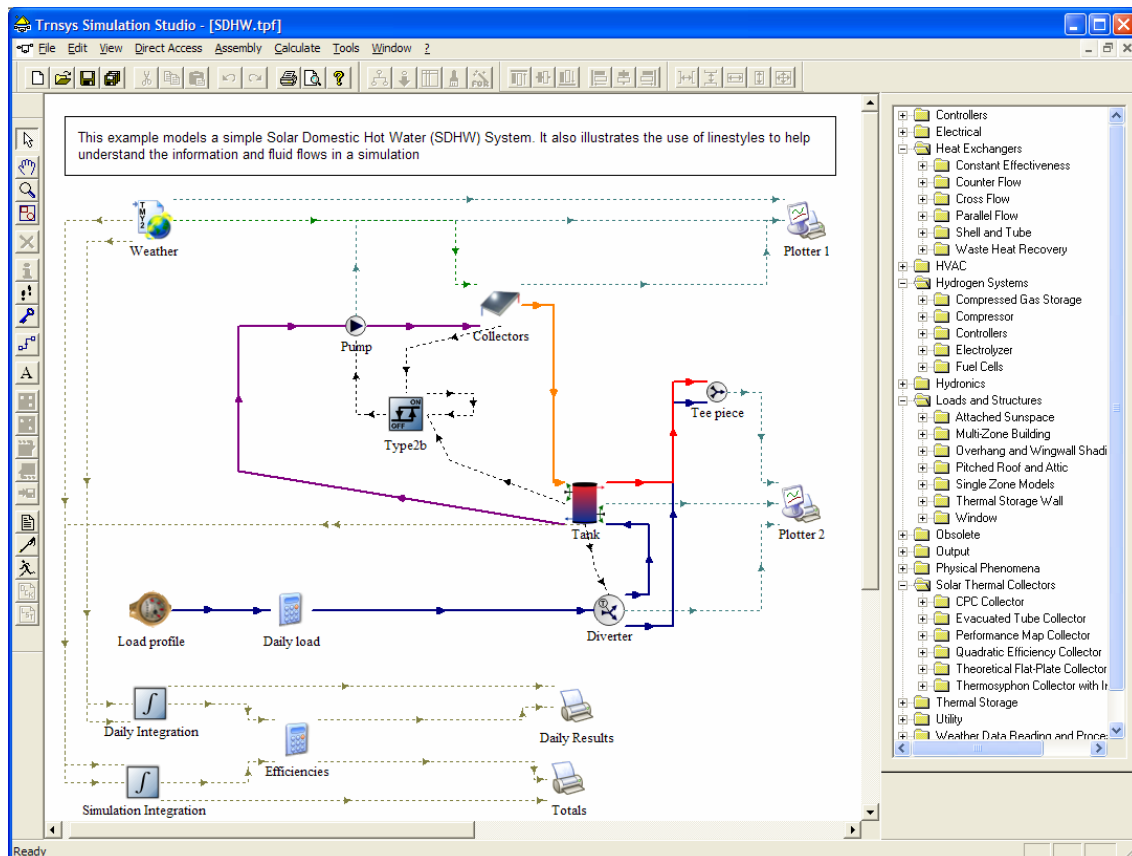


Figure 1: TRNSYS graphical interface

The simulation engine is programmed in Fortran and the source is distributed. The engine is compiled into a Windows Dynamic Link Library (DLL), TRNDll. The TRNSYS kernel reads all the information on the simulation (which components are used and how they are connected) in the TRNSYS input file, known as the deck file (*.dck). It also opens additional input files (e.g. weather data) and creates output files. The simulation engine is called by an executable program, TRNExe.exe, which also implements the online plotter, a very useful tool that allows you to view dozens of output variables during a simulation.

3 Model description

3.1 Case “TINE Meieriet Verdal”

When the development of TINE Meieriet Verdal is completed in 2012, it will have production lines for cheese, butter and whey powder. Different solutions for energy savings by use of water recovery tanks and heat pumps at the entire production plant was studied in 2010 (Rosenberg, 2010). The development of a generic TRNSYS model starts with the cheese production line. Treatment of by-products from this line, such as cream and whey, is not included in the model yet.

To facilitate the understanding of the model, a short description of the cheese production is included here with a schematic presentation of the process steps in figure

2; for more details see (Rosenberg, 2010). The dairy specific terms used are explained in chapter 5 “Nomenclature”.

Raw milk is transported to the dairy with tank lorries and is normally chilled from 7°C to 3°C by ice water in raw milk coolers and stored in silo tanks. The milk is pasteurized, cream is separated and a part of the skimmed milk is treated in a “Bactofuge”. Milk is added to a fermentation tank together with cream, rennet and a starter culture. In the cheese vats, the curd is formed by adding rennet that is an enzyme that acts on the milk proteins. After some time, the curd is cut with cheese knives into small pieces and the first drain of whey takes place. Warm water is added and the vat is heated to 36.8-39.3°C by steam. From the cheese vat the curd is pumped to the pre-press and the final press where the whey residue is removed and after that the cheese is formed and cut. After forming the cheese it salted with brine. The brine is chilled to 12.5°C by ice water. The maturing and storage of cheese is not included in the model, because it is independent of the energy/water recovery system.

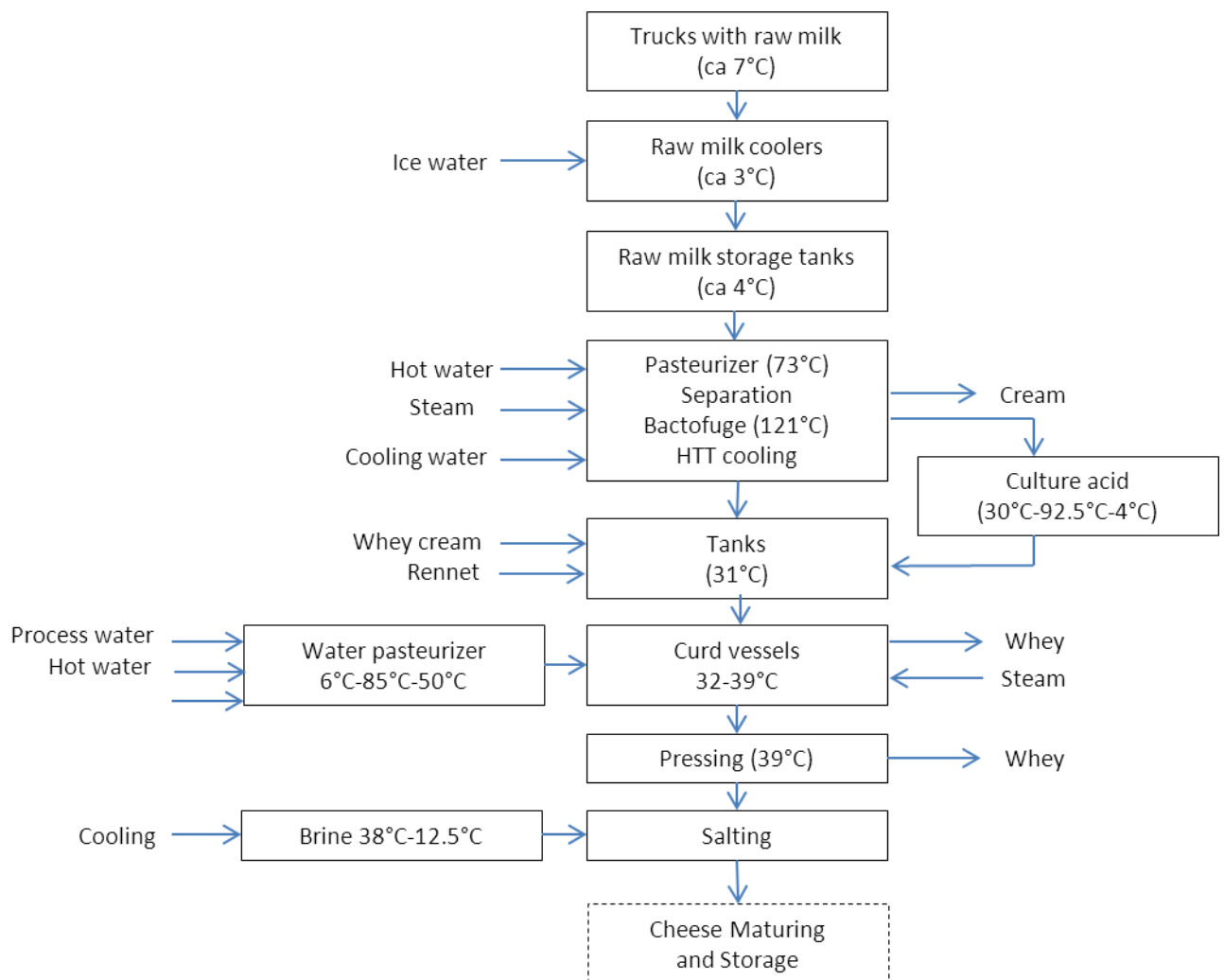


Figure 2: Schematic overview of the cheese production plant at TINE Meieriet Verdal

The TRNSYS model also includes automatic cleaning (two Clean-In-Place (CIP) systems belonging to the cheese production) and water used for sanitation and manual washing of premises and equipment. Space heating of the old part of the dairy is also included in the model.

The dairy has a water saving system with two storage tanks with a volume of 414 m³ each. The temperatures are 10°C and 30-35°C respectively in the storage tanks. In the existing system, storage water with a temperature of 30-35°C was used to heat milk in the cheese production from 4°C to 27°C, and the water was thus cooled to 8°C and stored in the 10°C –water storage tank. The 10°C-water was used for cooling in cream pasteurizers, whey pasteurizers, and culture acid pasteurizers and for cooling of oil compressors.

3.2 Calculation assumptions

The dairy used to have a steam system for most of the process plant, but most of the steam system is/will be rebuilt to a hot water system. In the cheese production plant the TRNSYS model assumes that the only processes using steam are the high temperature pasteurization and the reheating of curd water (this might be replaced by hot water, but it is not done yet in the model).

The steam is produced in the dairy boiler plant and has a temperature of 180°C and a pressure of 8 bars. The hot water is primarily supplied as district heat from a neighbour, but as a back-up the dairy may also produce hot water in two gas fired boilers. The temperature of the delivered district heat is 105°C and the temperature of the hot water system is assumed to be 97°C in the calculations.

Ice water is used for cooling below approx. 15°C (above this temperature recovered water may be used). The temperature of the ice water to the processes is assumed to be 1°C and the return temperature should be less than 6°C.

3.3 Description of the model adjusted to the case TINE Meieriet Verdal-cheese production

3.3.1 Introduction

So far, 22 different simulation models have been made for different cases relevant for the cheese production line at TINE Meieriet Verdal. 8 of these designs are not realistic since they would require a total reconstruction of the plant. The remaining 14 designs are briefly described below.

3.3.2 Case 2-2 (base case)

This configuration is more or less like the current design at TINE Meieriet Verdal. It includes 3 tanks for waste water recovery; respectively ice water, cooling water and economiser water tank. The average weekly tank temperatures for case 2-2 are:

- 5.5 °C, 12.2 °C and 26.3 °C

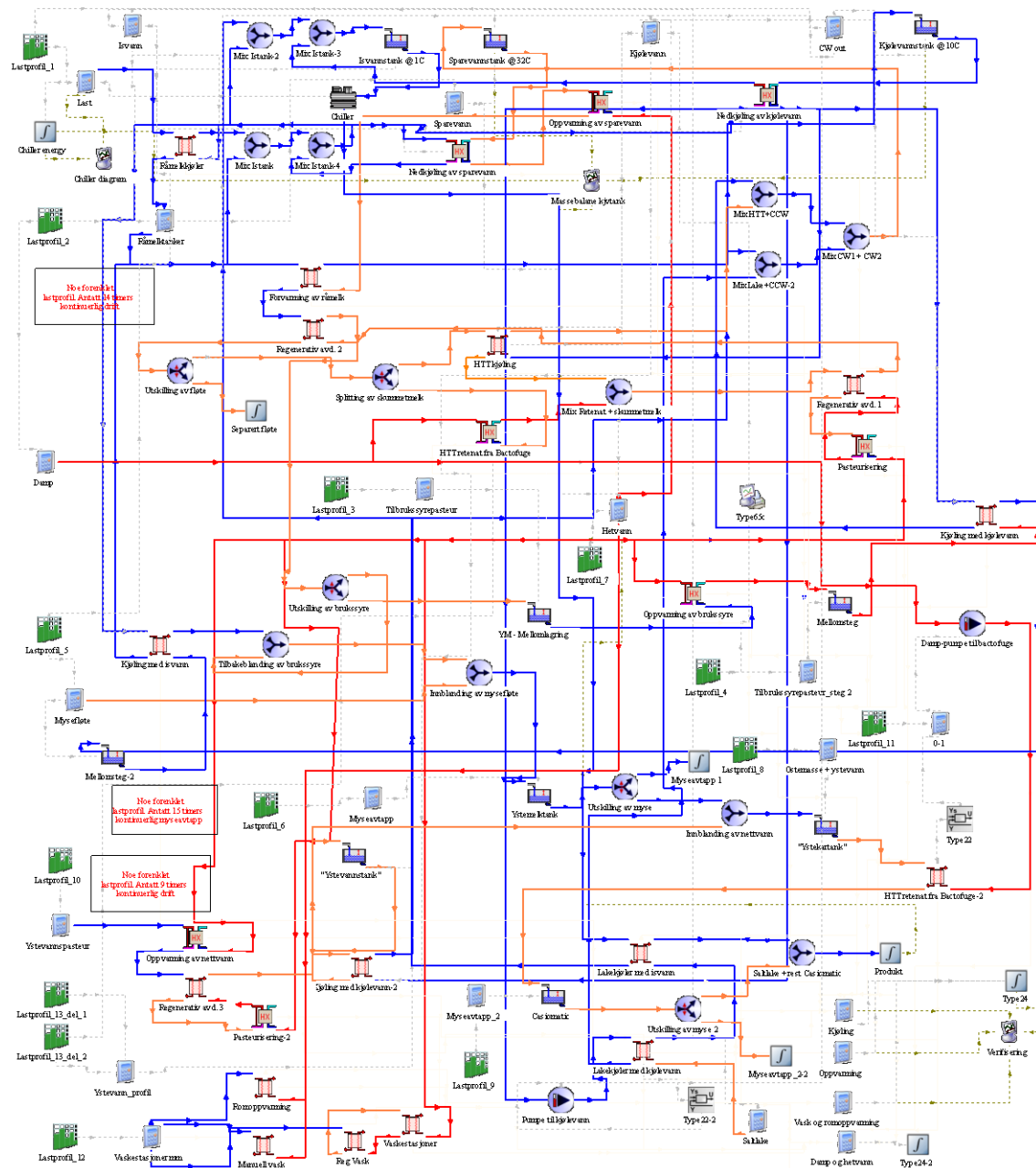


Figure 3: TRNSYS model for case 2-2

Figure 3 shows the TRNSYS model for case 2-2 (base case), and table 2 summaries the weekly energy consumption for the cheese production line for case 2-2.

Table 2: Energy consumption [MWh/week] for case 2-2

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	135.9	110.9	3.9	192.4	26.4	-

3.3.3 Case 3-1

The only difference between case 2-2 and case 3-1 is the addition of a new heat exchanger for heating of the water entering the economiser water tank (see figure 4). Surplus energy from the cheese production is used in the new heat exchanger. This modification gives the following tank temperatures:

- 5.5 °C, 12.2 °C and 29.5 °C

Table 3 summaries the weekly energy consumption for the cheese production line for case 3-1.

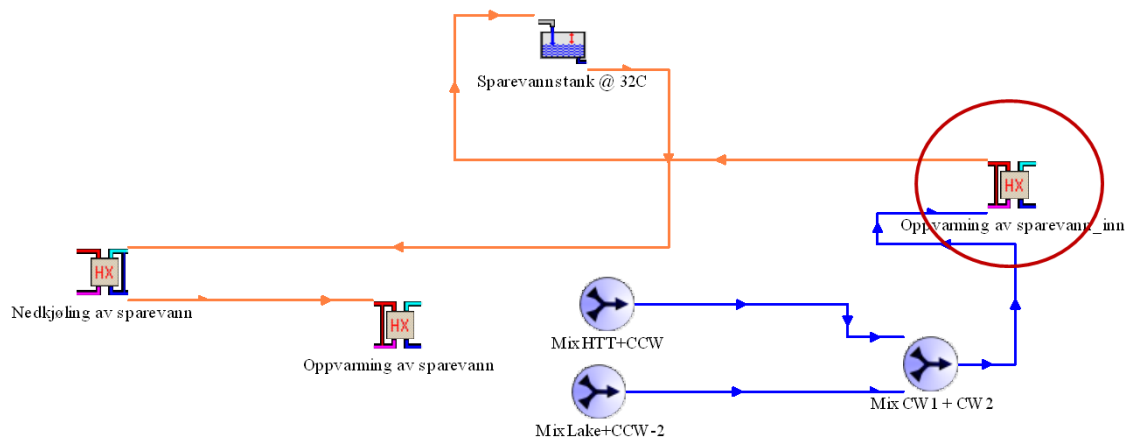


Figure 4: TRNSYS model for the case 3-1 (simplified version)

Table 3: Energy consumption [MWh/week] for case 3-1

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	135.9	110.9	3.9	175.6	26.4	-

3.3.4 Case 3-2

The only difference between case 3-1 and case 3-2 is the change of hot stream for heating of the water entering the economiser water tank. Surplus energy from two streams in the cheese production plant is used in the heat exchanger. This modification gives the following tank temperatures:

- 5.5 °C, 12.2 °C and 33.6 °C

Table 4 summaries the weekly energy consumption for the cheese production line for case 3-2.

Table 4: Energy consumption [MWh/week] for case 3-2

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	135.9	110.9	4.0	162.6	26.4	-

3.3.5 Case 3-3

The only difference between case 3-2 and case 3-3 is the addition of a new heat exchanger (see figure 5) for cooling of the water entering the economiser water tank (from 33.6 °C down towards 32 °C). Surplus energy from the cheese production is used in the new heat exchanger. This modification gives the following tank temperatures:

- 5.5 °C, 12.2 °C and 32.5 °C

Table 5 summaries the weekly energy consumption for the cheese production line for case 3-3.

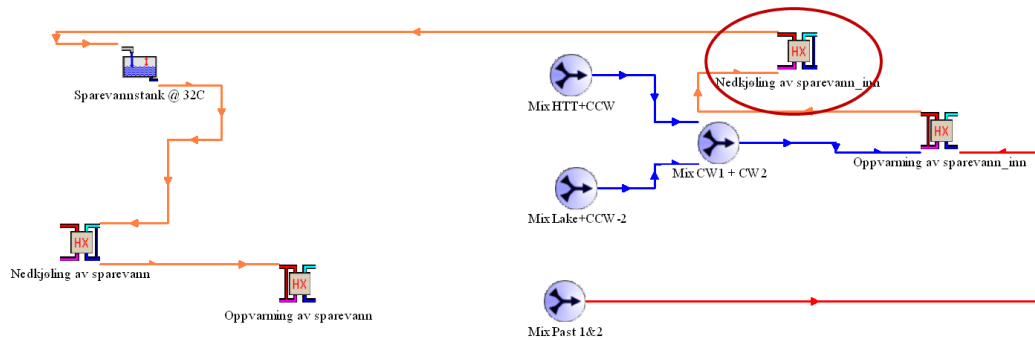


Figure 5: TRNSYS model for the case 3-3 (simplified version)

Table 5: Energy consumption [MWh/week] for case 3-3

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	135.9	110.9	3.9	162.7	26.4	-

3.3.6 Case 3-4-0

The only difference between case 3-3 and case 3-4-0 is the change of cold stream for cooling of the water entering the economiser water tank (from 33.6 °C down towards 32 °C). Surplus energy from the cheese production is used this heat exchanger. The modification gives the following tank temperatures:

- 5.5 °C, 12.2 °C and 31.3 °C

Table 6 summaries the weekly energy consumption for the cheese production line for case 3-4-0.

Table 6: Energy consumption [MWh/week] for case 3-4-0

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	135.9	110.9	3.9	162.9	26.4	-

3.3.7 Case 3-4-1

The main difference between 3-4-0 and 3-4-1 is that economiser water is used for cooling of skimmed milk (see figure 6) instead of cooling water (in the heat exchanger called HTT kjøling). In addition, a modification to the heat exchanger is made (increased area). The following average weekly temperatures are obtained:

- 5.5 °C, 12.1 °C and 31.6 °C

Table 7 summaries the weekly energy consumption for the cheese production line for case 3-4-1.

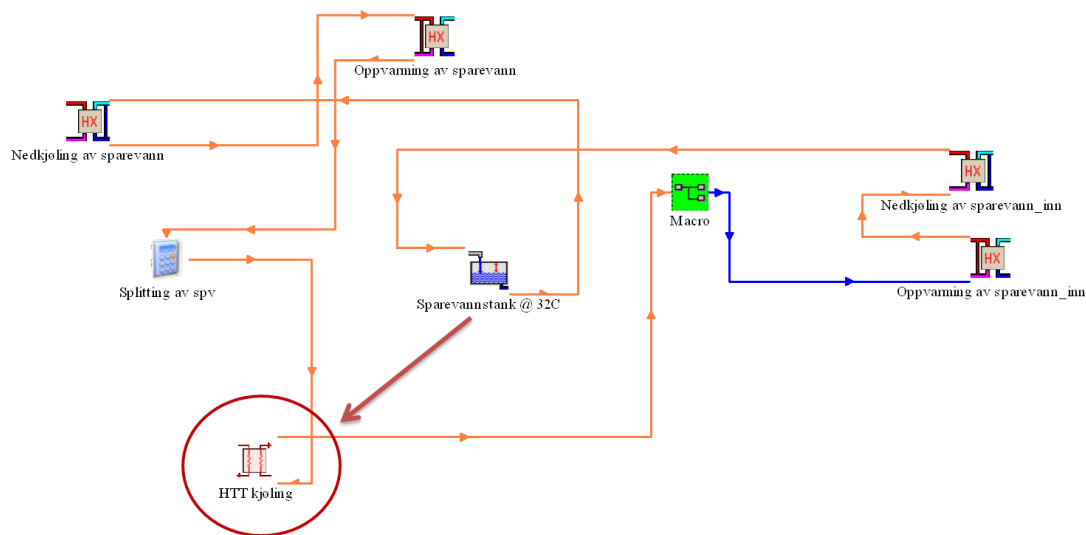


Figure 6: TRNSYS model for the case 3-4-1 (simplified version)

Table 7: Energy consumption [MWh/week] for case 3-4-1

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	136.0	110.9	2.9	162.9	26.4	-

3.3.8 Case 3-4-2

The main difference between 3-4-1 and 3-4-2 is that economizer water is used for cooling of ystevann (water used in the cheese factory) instead of cooling water (see

figure 7). In addition, a modification to the heat exchanger is made (increased area). The following average weekly temperatures are obtained:

- 5.5 °C, 12.0 °C and 31.5 °C

Table 8 summaries the weekly energy consumption for the cheese production line for case 3-4-2.

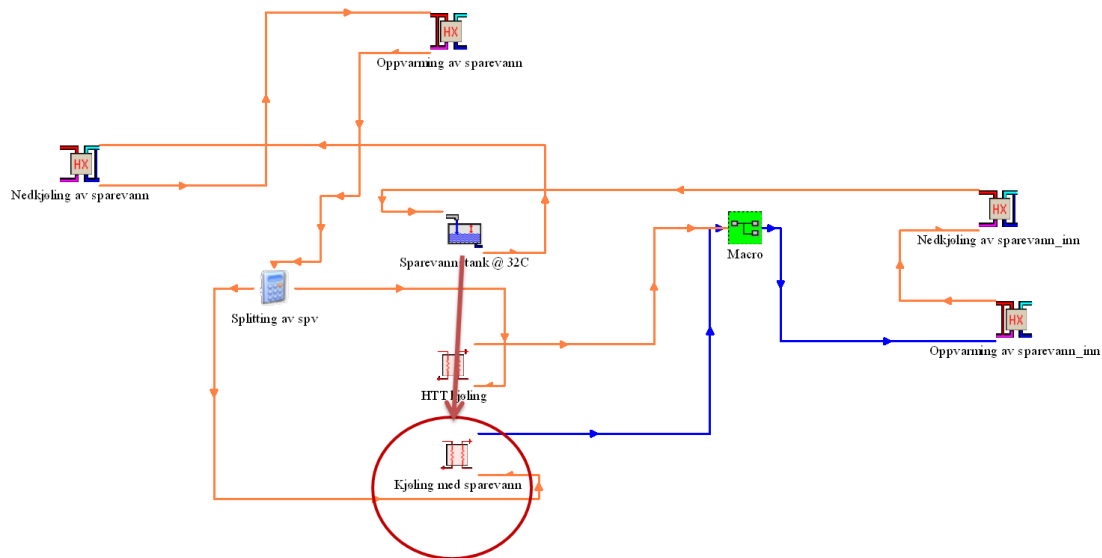


Figure 7: TRNSYS model for the case 3-4-2 (simplified version)

Table 8: Energy consumption [MWh/week] for case 3-4-2

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	136.0	110.9	2.7	163.0	26.4	-

3.3.9 Case 3-4-3

The main difference between 3-4-2 and 3-4-3 is that economizer water is used for cooling of acid (*brukssyre*) in addition to cooling water. As a consequence, an additional heat exchanger is installed (see figure 8). The following average weekly temperatures are obtained:

- 5.5 °C, 12.0 °C and 31.5 °C

Table 9 summaries the weekly energy consumption for the cheese production line for case 3-4-3.

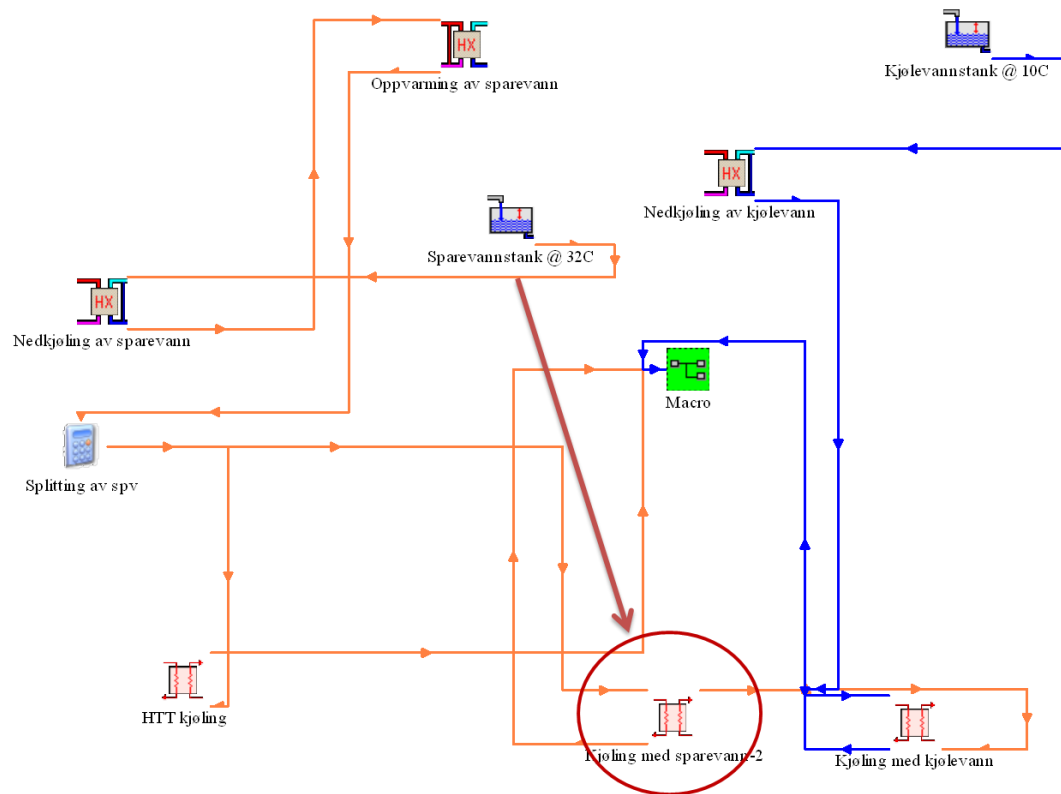


Figure 8: TRNSYS model for the case 3-4-3 (simplified version)

Table 9: Energy consumption [MWh/week] for case 3-4-3

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.2	136.0	110.9	2.7	163.3	26.4	-

3.3.10 Case 3-4-4

The main difference between 3-4-4 and 3-4-3 is that cooling of incoming and outgoing economizer water is removed (see figure 9). As a consequence, two heat exchangers are removed. The following average weekly temperatures are obtained:

- 5.5 °C, 12.1 °C and 32.9 °C

Table 10 summaries the weekly energy consumption for the cheese production line for case 3-4-4.

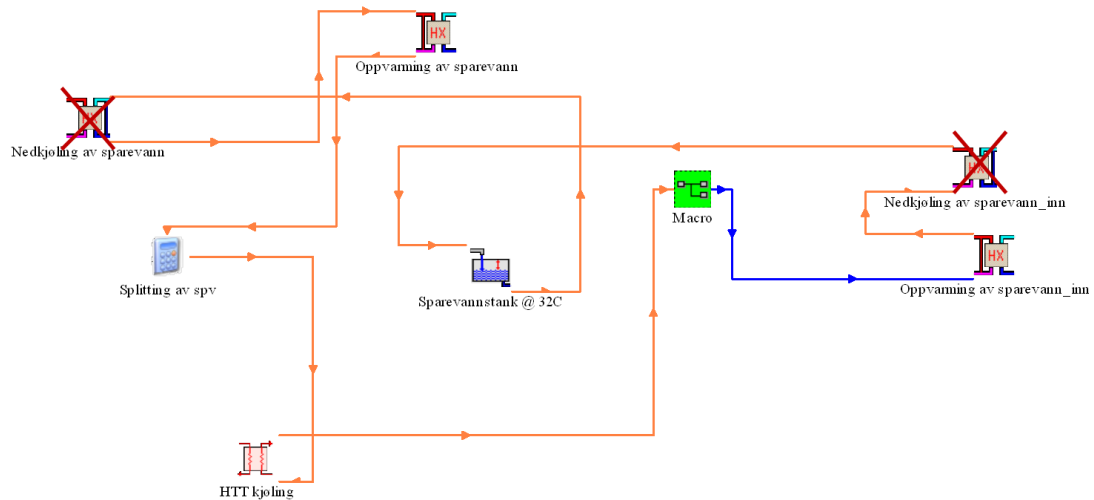


Figure 9: TRNSYS model for the case 3-4-4 (simplified version)

Table 10: Energy consumption [MWh/week] for case 3-4-4

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
45.9	136.0	110.9	2.8	162.6	26.0	-

3.3.11 Case 3-4-5

The main difference between 3-4-5 and 3-4-4 is that cooling of exiting cooling water is removed. As a consequence, one heat exchanger is removed (see figure 10). This also means that the cooling water is kept at a higher temperature than 10 °C. The following average weekly temperatures are obtained in the three tanks:

- 6.9 °C, 12.1 °C and 33.0 °C

Table 11 summaries the weekly energy consumption for the cheese production line for case 3-4-4.

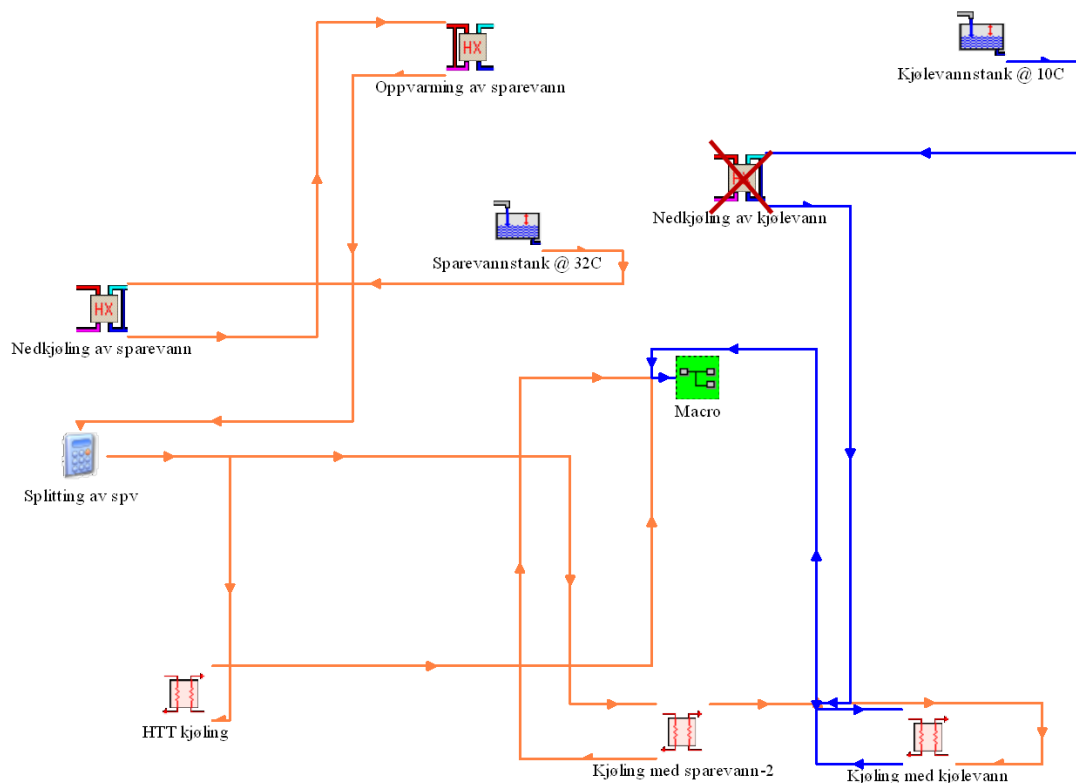


Figure 10: TRNSYS model for the case 3-4-5 (simplified version)

Table 11: Energy consumption [MWh/week] for case 3-4-5

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
45.9	135.9	110.9	2.6	162.0	26.1	-

It should be noted that the only negative consequence of allowing a higher cooling water temperature, was that the final temperature of the acid (brukssyre) was 22.4 °C instead of 21 °C. However, by increasing the cooling water flowrate or increasing the area of the heat exchanger, the temperature can be brought back to its set-point.

3.3.12 Case 3-4-6

This case is the same as 3-4-5, but modified so that the final temperature of the acid (brukssyre) is 21.0 °C. This is accomplished by increasing the area in the relevant heat exchanger. The average weekly temperatures are the same as in case 3-4-5, and the energy consumption is also the same.

3.3.13 Case 3-4-7

The main difference between 3-4-7 and 3-4-6 is that heating of the exiting economizer water is removed (see figure 11). As a consequence, one heat exchanger is removed. This also means that the temperature of the economizer water is varying, and not kept

constant at 32 °C. The following average weekly temperatures are obtained in the three tanks:

- 6.9 °C, 11.9 °C and 32.9 °C

Table 12 summaries the weekly energy consumption for the cheese production line for case 3-4-7.

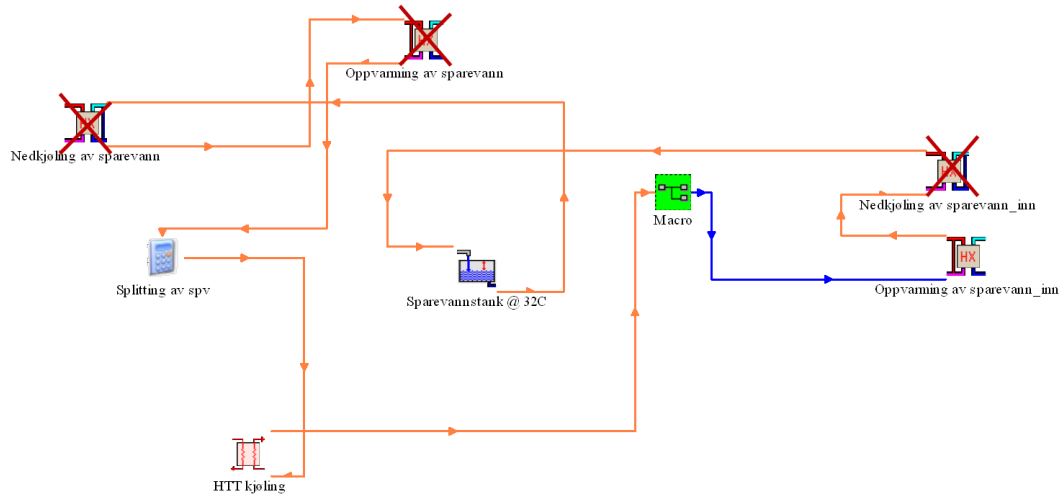


Figure 11: TRNSYS model for the case 3-4-7 (simplified version)

Table 12: Energy consumption [MWh/week] for case 3-4-7

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
46.3	135.6	110.9	2.6	159.6	26.8	-

It should be noted that there are some negative consequences of allowing a varying economizer water temperature. In two of the heat exchangers in the cheese production plant, the product temperatures deviate +/- 1 °C of the target temperature. However, this can be controlled by increasing/decreasing the flow rate of the economizer water.

3.3.14 Case 4-1-0 (with heat pump)

Case 4-1-0 is based on case 3-4-7, but an additional water tank is installed (see figure 12). The target value for this tank temperature is approximately 50 °C. A heat pump is installed between three of the tanks, where the economizer water is the inlet stream to the heat pump. A generic TRNSYS model is used for the heat pump (based on catalog data of an R134a vapor compression heat pump), something that will be changed in later versions of the simulation model. The following average weekly temperatures are obtained in the four tanks:

- 6.8 °C, 6.4 °C, 33.5 °C and 48.1 °C

Table 13 summaries the weekly energy consumption for the cheese production line for case 4-1-0.

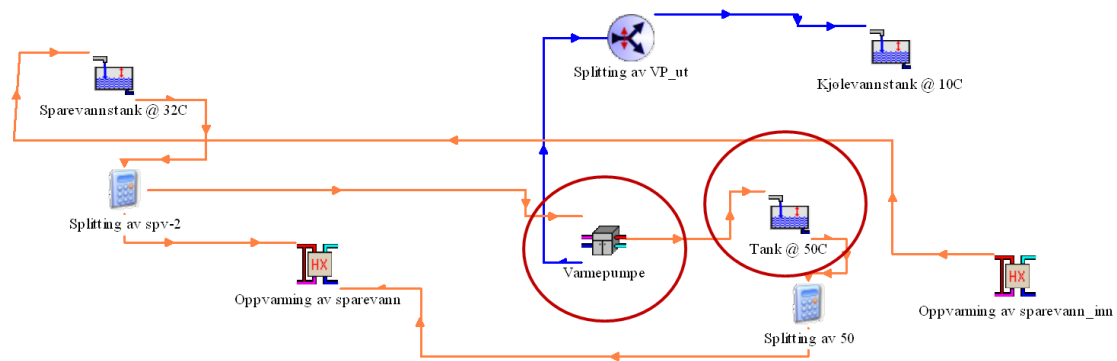


Table 13: Energy consumption [MWh/week] for case 4-1-0

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
45.5	133.9	110.9	2.6	159.3	27.3	9

It should be noted that the total weekly energy consumption actually increased when installing the heat pump. This clearly means that the installed heat pump is not suitable for the given application. It should also be noted that the outlet temperatures in the ice water exchangers were too low.

3.3.15 Case 4-1-1 (with heat pump)

The main difference between 4-1-1 and 4-1-0 is that the outlet temperatures in the ice water exchangers are optimised. The following average weekly temperatures are obtained in the four tanks:

- 7.6 °C, 6.4 °C, 33.5 °C and 48.1 °C

Table 14 summaries the weekly energy consumption for the cheese production line for case 4-1-1.

Table 13: Energy consumption [MWh/week] for case 4-1-1

Cooling	Heating	Washing and space heating	Chiller	Hot water	Steam	Heat pump
45.1	133.9	110.9	2.5	159.3	27.3	9

It should be noted that the total weekly energy consumption once again is higher than without the heat pump. This clearly means that the installed heat pump is not suitable for the given application.

3.4 Summary of the simulation results

Table 14 gives a summary of the simulation results for the most relevant designs of the cheese production plant at TINE Meieriet Verdal. As one can see, case 3-4-7 shows a huge potential for reduction of the energy consumption compared to the base case (2-2).

Table 14: Summary of the simulation results

Case	Chiller [MWh/week]	Hot water [MWh/week]	Steam [MWh/week]	H-Pump [MWh/week]	Milk [kg/week]	Cheese [kg/week]
2-2	3.9	192.4	26.4	0.0	2381000	465579
3-1	3.9	175.6	26.4	0.0	2381000	465579
3-2	4.0	162.6	26.4	0.0	2381000	465579
3-3	3.9	162.7	26.4	0.0	2381000	465579
3-4-0	3.9	162.9	26.4	0.0	2381000	465579
3-4-1	2.9	162.9	26.4	0.0	2381000	465579
3-4-2	2.7	163.0	26.4	0.0	2381000	465579
3-4-3	2.7	163.3	26.4	0.0	2381000	465579
3-4-4	2.8	162.6	26.0	0.0	2381000	465579
3-4-5	2.6	162.0	26.1	0.0	2381000	465579
3-4-6	2.6	162.0	26.1	0.0	2381000	465579
3-4-7	2.6	159.6	26.8	0.0	2381000	465579
4-1-0	2.6	159.3	27.3	9.0	2381000	465579
4-1-1	2.5	159.3	27.3	9.0	2381000	465579

In addition, several heat exchangers have been removed in case 3-4-7 compared to the base case design. This just emphasizes the advantage of this design. Case 4-1-0 and 4-1-1 are the only two designs that include a heat pump. However, the total weekly energy consumption increased due to the installation of the heat pump. The reason is either that the installed heat pump is not suitable for the application, or that the heat pump operates above or below the pinch point, something that should never be done. A heat pump should always be integrated across the pinch point in order to save energy. In such a design, heat is pumped from the part of the process which is overall a heat source to the part which is overall a heat sink.

Table 15 gives a summary of the specific energy consumption for the most relevant designs of the cheese production plant at TINE Meieriet Verdal. In the second column, the total electricity consumption is divided by the amount of milk entering the cheese production plant. In the third column, the total electricity consumption is divided by the amount of cheese produced. In the fourth column, the total thermal energy consumption is divided by the amount of milk entering the production plant. In the fifth column, the total thermal energy consumption is divided by the amount of cheese produced. Once again, case 3-4-7 is the best design regarding all categories. If one considers the specific energy consumption for case 4-1-0 and 4-1-1 (both with a heat pump), the specific thermal energy consumption actually increased compared to case 3-4-7. This once again confirms that the integration of the heat pump is wrong.

Table 15: Summary of the simulation results

Case	el/milk [kWh/kg]	el/cheese [kWh/kg]	therm/milk [kWh/kg]	term/cheese [kWh/uke]
2-2	0.0016	0.0083	0.0919	0.4700
3-1	0.0016	0.0083	0.0848	0.4339
3-2	0.0017	0.0085	0.0794	0.4060
3-3	0.0016	0.0084	0.0794	0.4062
3-4-0	0.0016	0.0083	0.0795	0.4067
3-4-1	0.0012	0.0062	0.0795	0.4066
3-4-2	0.0011	0.0058	0.0795	0.4067
3-4-3	0.0011	0.0058	0.0796	0.4073
3-4-4	0.0012	0.0059	0.0792	0.4051
3-4-5	0.0011	0.0056	0.0790	0.4041
3-4-6	0.0011	0.0055	0.0790	0.4041
3-4-7	0.0011	0.0055	0.0783	0.4004
4-1-0	0.0048	0.0248	0.0784	0.4008
4-1-1	0.0048	0.0246	0.0784	0.4008

4 Conclusion and further work

As demonstrated in the previous chapters, TRNSYS is a suitable tool for analysing the energy saving potential for different food industries. As shown in table 15 for the cheese production plant at TINE Meieriet Verdal, it is possible to reduce the specific energy consumption by better use of the existing resources within the plant. The different simulation models (or cases) comply very well with the measured (or calculated?) energy consumption at the actual plant. A deviation of only 1-2 % in the total energy consumption is experienced.

However, there are some remaining tasks that need to be fulfilled in order to have an appropriate simulation model for the cheese production plant. As shown in table 16, there are some heat exchangers that have too low temperature differences at the different ends of the exchangers. We are also uncertain about the water temperature in the hot water system. At the moment, we have assumed that this temperature is 97 °C. However, it is likely that this temperature is higher, something that will make it easier to obtain a realistic temperature difference in some of the heat exchangers.

Another remaining task is the correct integration of a heat pump for the cheese production plant. As demonstrated in tables 14 and 15, the specific energy consumption actually increased when a heat pump was installed. This is either due to wrong integration of the heat pump, or that the heat pump installed was unsuitable for the application. A remaining task is therefore to install a suitable heat pump and integrate it correctly.

Table 16: Summary of temperatures and temperature differences in different heat exchangers

HX	T_hot_in C	T_hot_out C	T_cold_in C	T_cold_out C	dTin K	dTout K	LMTD K	Q kW	UA kW/K	Comments
Ystemelkpasteur - Råmelkkjøler	7.0	3.0	1.0	6.9	0.1	2.0	0.6	131.5	207.2655	
Ystemelkpasteur - Forvarming av råmelk	32.0	12.2	4.0	27.0	5.0	8.2	6.5	624.2	96.5	
Ystemelkpasteur - Regenerativ avd 2	58.0	31.2	27.0	53.0	5.0	4.2	4.6	706.4	153.95	
Ystemelkpasteur - Regenerativ avd 1	73.0	58.0	53.0	68.0	5.0	5.0	5.0	394.5	78.9	
Ystemelkpasteur - Pasteurisering	97.0	75.3	68.0	73.0	24.0	7.3	14.0	0.0		eff=0,75. (Use Q to determine UA)
HTT - HTT kjøling	53.0	43.9	10.0	19.6	33.4	33.9	33.6	211.7	6.292	
HTT - HTT rentetat fra bactofove	170.4	94.1	53.0	120.2	50.2	41.1	45.5	0.0		eff=0,65. (Use Q to determine UA)
HTT - HTT rentetat fra bactofove 2	170.4	37.0	36.5	39.3	131.1	0.5	23.5	70.4		3 Necessary with steam?
Brukssyrepasteur - kjøling med kjølevann	91.8	21.0	10.0	17.5	74.3	11.0	33.1	164.7	4.97	
Brukssyrepasteur - oppvarming av brukssyre	97.0	34.0	30.0	92.5	4.5	4.0	4.2	0.0		eff=0,94. (Use Q to determine UA)
Brukssyrepasteur - kjøling med isvann	21.0	4.0	1.0	18.0	3.0	3.0	3.0	80.7	26.9	
Ystevannspasteur - oppvarming av nettvann	97.0	28.8	6.0	33.0	64.0	22.8	39.9	0.0		eff=0,75. (Use Q to determine UA)
Ystevannspasteur - regenerativ avd 3	85.0	65.0	33.0	53.0	32.0	32.0	32.0	179.4	5.605	
Ystevannspasteur - pasteurisering 2	97.0	64.0	53.0	85.0	12.0	11.0	11.5	0.0		eff=0,75. (Use Q to determine UA)
Ystevannspasteur - kjøling med kjølevann 2	65.0	50.0	10.0	19.7	45.3	40.0	42.6	367.7	8.632	
Ystevannspasteur - kjøling med kjølevann 2	65.0	50.0	10.0	52.9	12.1	40.0	23.3	201.4	8.632	
Lake - lakekjøler med isvann	15.0	10.0	1.0	3.5	11.5	9.0	10.2	4.0	0.396	
Lake - lakekjøler med kjølevann	38.0	15.0	10.0	27.1	10.9	5.0	7.6	18.9	2.5	
Romoppvarming - romoppvarming	97.0	32.9	6.0	70.0	27.0	26.9	26.9	195.2	7.242	
Manuell vask - manuell vask	97.0	37.9	6.0	65.0	32.0	31.9	31.9	223.9	7.008	
Vaskestasjoner - reg vask	92.0	68.0	6.0	30.0	62.0	62.0	62.0	94.0	1.5165	
Vaskestasjoner - vaskestasjoner	97.0	34.9	30.0	92.0	5.0	4.9	4.9	247.7	50.052	

5 Nomenclature

English	Norwegian	Explanation
Brine	Lake	Liquid solution of salt
CIP	Vaskestasjon	Clean-In-Place (automated cleaning of equipment)
Curd	Ostemasse	Intermediate product in cheese production (coagulated milk with rennet)
HTT	HTT	High Temperature Treatment (pasteurising)
Rennet	Løpe	Enzyme used in cheese production
Whey	Myse	By-product in cheese production (the remaining liquid after milk has been curdled)
TRNSYS		TRaNsient SYstems Simulation Program

6 References

Rosenberg, E., CREATIV DX3.2.4 Case Study TINE Meieriet Verdal, IFE/KR/F-2010/172, Kjeller, November 2010

Appendix 1 Cheese production line at TINE Meieriet Verdal

