

ENERGY CONSUMPTION FOR SALMON SLAUGHTERING PROCESSES

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ABSTRACT

Today's slaughtering and processing method for Atlantic salmon (*Salmo salar*) using large refrigerated seawater (RSW) and buffer tanks before and during a stepwise processing regime has now reached its limits. To overcome this problem, the salmon industry must, like the poultry industry, move towards automated online production, where the animal is quickly processed so all the energy (cooling and transport) can be focused on the meat only and not the surrounding water/ice and carcass. It is of importance to quantify the total energy consumption related to chilling and transport of Atlantic salmon. This enables to foresee and compare the energy requirements, costs and environmental impacts related to existing and new chilling technologies. A modern large slaughter facility in Norway that slaughter up to 125 000 tonnes of Atlantic salmon per year uses RSW tanks for fish cooling with a typical volume of 200-280 m³. This results in a significant amount of energy consumption for refrigeration. The objective of this paper was to describe the current situation at three different salmon slaughterhouses. The energy consumption were estimated and compared. In 2015, the specific energy consumption for these facilities were 105.7, 103.1 and 85.1 kWh/tonne, respectively. The refrigeration systems use ammonia as refrigerant, which is common in food processing industry in Norway.

Keywords: energy consumption, measurements, ammonia, chilling technologies, Atlantic salmon

1. INTRODUCTION

Seafood processing has historically been an important industry in Norway. In 2015, Norwegian salmon industry produced 1,303,346 tonnes of salmon of which 1,033,397 tonnes were exported mainly to Europe (80%) (Statistics Norway, 2016a). In the same year, seafood processing accounted for 1152 GWh electricity consumption (Statistics Norway, 2016b). This was the highest (23 %) among other industries such as feed, meat and dairy production (Figure 1). The amount of catch- and farmed seafood totaled 3,715,405 tonnes [Statistics Norway, 2016c, 2016d]. These figures indicated an average specific energy consumption of 310 kWh/tonne for the whole seafood processing industry in Norway in 2015.

ENOVA performed energy consumption surveys with up to 105 Norwegian seafood companies between 2006 and 2009. Average specific energy consumption at the interviewed fish slaughterhouses were 181, 132, 112 and 99 kWh/tonne, for each of the years between 2006 and 2009 (Enova, 2007–2010). Knowledge on energy consumption for fish slaughtering steps is relatively scarce in scientific literature and reports. Helgerud (2007) reported that cooling or freezing processes constitute the largest proportion (69 %) of total energy consumption in fish processing plants. Distribution of energy consumption by the remaining operations were ventilation (10 %), pumping (4 %), space heating (3 %), pressurized air (3 %), illumination (2 %), and unspecified (9 %). However, specific distribution of energy consumption by fish slaughtering steps such as stunning/killing, bleeding, gutting, washing, ice production, packaging and cold storage have not been shown in any reports yet.

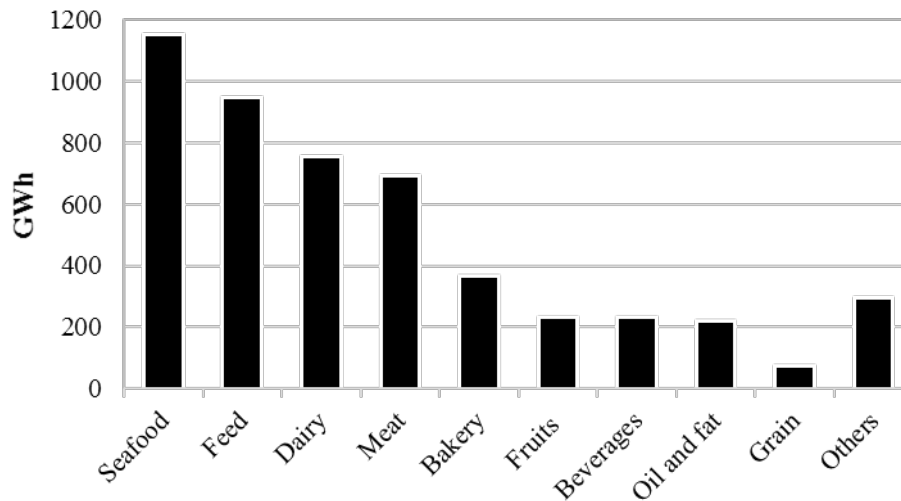


Figure 1. Distribution of energy consumption in Norwegian food industry in 2015 [2]

A thorough analysis of existing technologies is necessary for benchmarking when assessing the feasibility of new technologies. This paper therefore aims to assess the current energy situation at selected Norwegian salmon processing plants.

2. SYSTEMS AND METHODS

Three salmon processing plants in different geographical locations representing the southern, central and northern coastline of Norway were selected for this study.

2.1 System description

The different processing steps in salmon plants are visualized in Figure 2. The fish gathered in sea cages are stunned and killed sequentially. Plant *Central* uses tanks filled with refrigerated seawater (RSW) for live chilling of salmon before stunning and killing. Other plants (*South* and *North*) starts slaughtering of salmon without precooling. As a next step, bleeding takes place in RSW tanks which normally takes 30 minutes before mechanical gutting and again washing in RSW tanks which lasts approx. 25 minutes. Some of the processed salmon is packed as whole fish and some is stored in pre-fillet RSW chilling tanks before the secondary process of filleting takes place. Both fillets and whole fish are packed into expanded polystyrene (EPS) boxes with ice and they are mainly transported by trucks to Europe.

The refrigeration systems at the processing plants use ammonia as refrigerant. At the central processing plant, there are two separate systems; one for RSW and one for ice production. Both have screw compressors, 2.5 MW for RSW and 1 MW for ice production. The condensers are cooled with seawater, where the water comes from a depth of 120 m, which gives a stable, low temperature over the year. Some of the heat from the refrigeration system are used for heating of washing water.

2.2 Total energy consumption in plants

Yearly energy consumption (MWh) was obtained from two of the salmon processing plants. Plants used electricity for all of the production steps. Information on production volumes was also given by the processing plants. The specific energy consumption of the plants was calculated (kWh/tonne of finished product). The fish temperature when it arrived to the plant was estimated to be 0.1 °C above the seawater temperatures (Skjervold, 2002). The theoretical heat load from the fish inside the cooling tanks were calculated based on start and end temperatures of the fish and with equations and parameters from ASHRAE Refrigeration, chapter 9 (2006). The three slaughtering plants operates with different end temperatures, but for comparison, the same end temperature was also used in a calculation of average values.

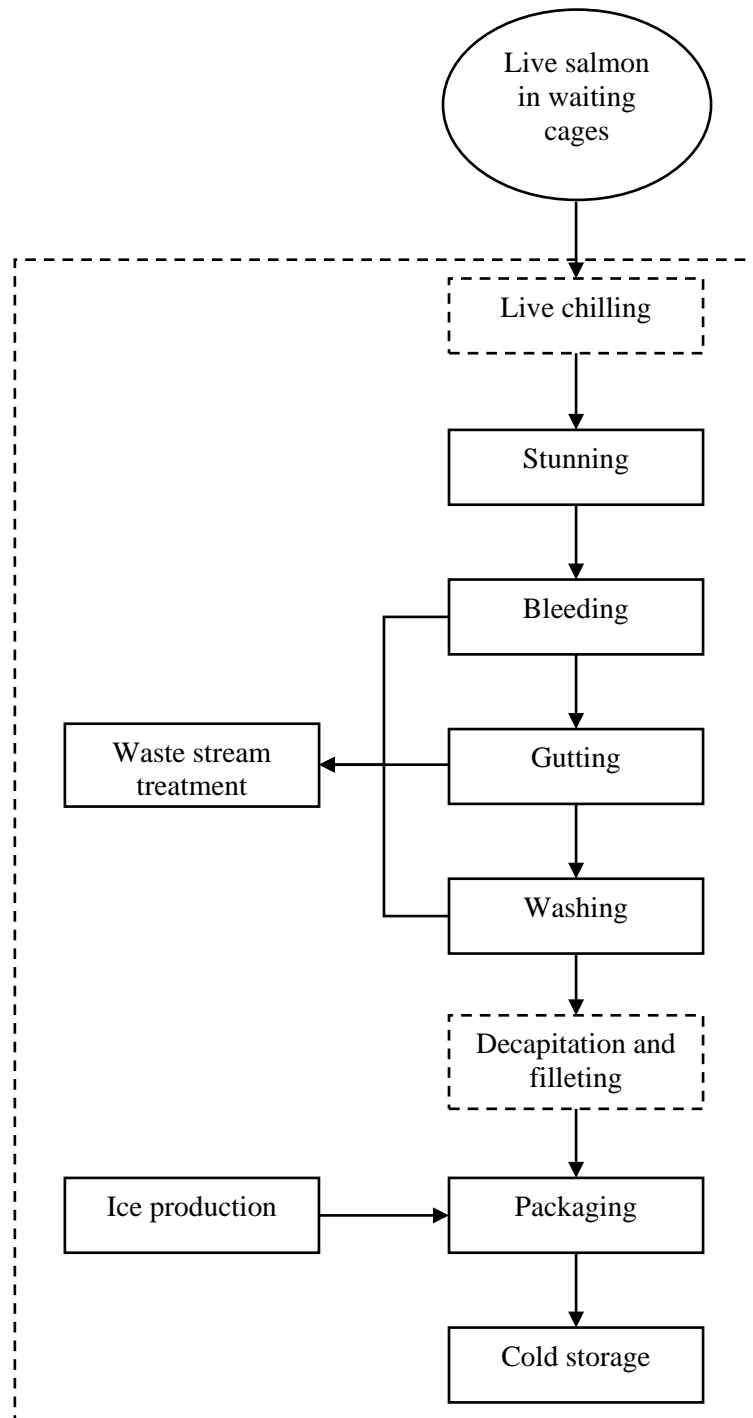


Figure 2. Main unit operations in salmon slaughtering process

¹ Boxes with dotted lines are only performed at Plant *Central*.

2.3 Energy consumption by main unit operations

Hourly energy consumption (kWh/h) by each unit operation in Plant *South* was estimated with amperage measurements at a full capacity production time using a current clamp (Fluke, USA). Three-phase power equation (Eq. 1) was used for estimation of energy consumption by the equipment. Calculations for Plants *Central* and *North* were mainly done using the Eq. 2 unless stated otherwise. Data required for the calculations was provided by the facilities.

$$E = \sqrt{3} \times U \times I \times \cos \theta \times 10^{-3} \quad (1)$$

$$E = \eta \times P \quad (2)$$

Where E : hourly energy consumption (kWh/h), U : voltage (V), I : current (A), $\cos \theta$: power factor (assumed to be 0.93), η : motor efficiency (assumed to be 0.8) and P : motor power in kW.

For estimation of the average specific energy consumption (kWh/tonne), obtained values were divided by the hourly production volume at the respective facility.

Amperage measurements for cooling of RSW (bleeding and washing tanks) were recorded with 10 s intervals over a week at Plant *South* during late June, 2016 using an industrial scopemeter (Fluke, USA). This was done in order to assess the energy consumption over a time period. For estimation of specific power consumption (kWh/tonne), obtained values was divided by the hourly production volume.

3. RESULTS AND DISCUSSION

Data for energy consumption was from three different salmon slaughtering plants. The results are shown in this section.

3.1 Total energy consumption in plants

Calculated yearly specific energy consumption for the plants are shown in Table 1. These values represent the energy consumption by all activities in the slaughtering plants; hence, they are depending on several factors.

Table 1. Specific energy consumption for 2015.

	Plant South	Plant Central	Plant North	
Average yearly energy consumption (2015)	105.7	103.1	85.1	kWh/tonne

The monthly specific energy consumption (kWh/tonne) at Plants *South* and *Central* for 2015 are shown in Figures 3 and 4. As for Plant *North*, there is no monthly data available, only yearly.

Plant *South* had the lowest power consumption during May and June (85.3 and 83.8 kWh/tonne) and highest consumption during January and October (126.8 and 130.7 kWh/tonne). Furthermore, Plant *Central* consumed lowest energy during November and December (90 and 91.8 kWh/tonne) and highest energy during February and June (119.3 and 136 kWh/tonne) (Figure 4). Plant *South* had no or very low production during February, August and September. This is due to differences in raw material supply and summer holiday in the facility.

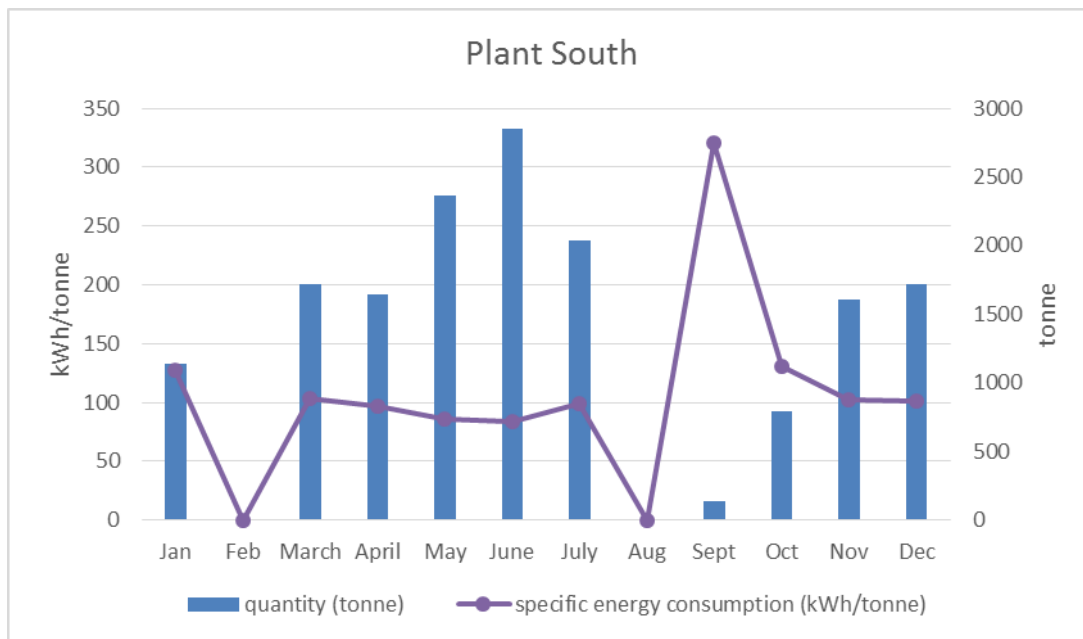


Figure 3. Monthly specific energy consumption (kWh/tonne) and production (tonne) of Plant *South* in 2015

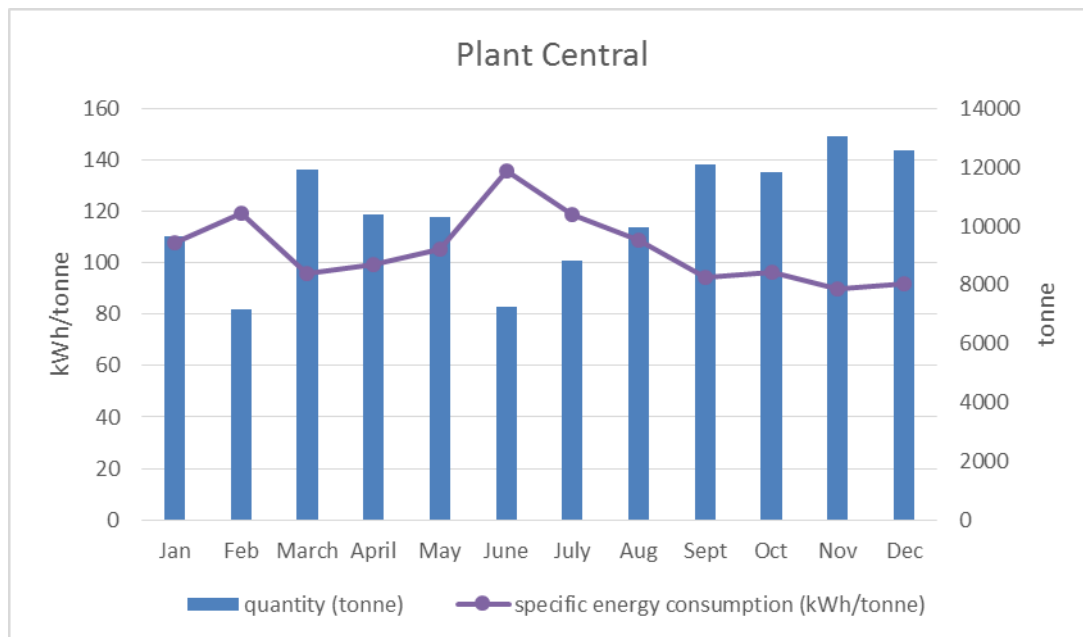


Figure 4. Monthly specific energy consumption (kWh/tonne) and production (tonne) of Plant *Central* in 2015

3.2 Energy consumption by main unit operations

The data was collected from the plants during November – December 2015. Production volumes (for this period) for Plant *South*, *Central* and *North* were 11.3, 29.0 and 17.9 ton/h, respectively. Specific energy consumption by different salmon slaughtering steps at three different plants are depicted in Figure 5. Results clearly showed that RSW cooling and ice production represented the highest fraction of energy requirement in all slaughterhouses. On average, 70.7 % of energy consumption (related to processing) was used for cooling of RSW, ice production and cold storage. This was in agreement with Helgerud (2007) that showed cooling or freezing processes constitute 69 % of total energy consumption in fish processing plants.

Results shown in Figure 5 indicate that different processes such as stunning/killing, gutting, packaging and waste treatment did not vary significantly in energy consumption with respect to each plant. Specific energy consumption for cooling processes (RSW chilling and cold storage) was slightly lower when the plant is located in further north of Norway. This could be due to lower initial fish/sea temperatures in the northern parts of Norway. Hence, a lower cooling load is required.

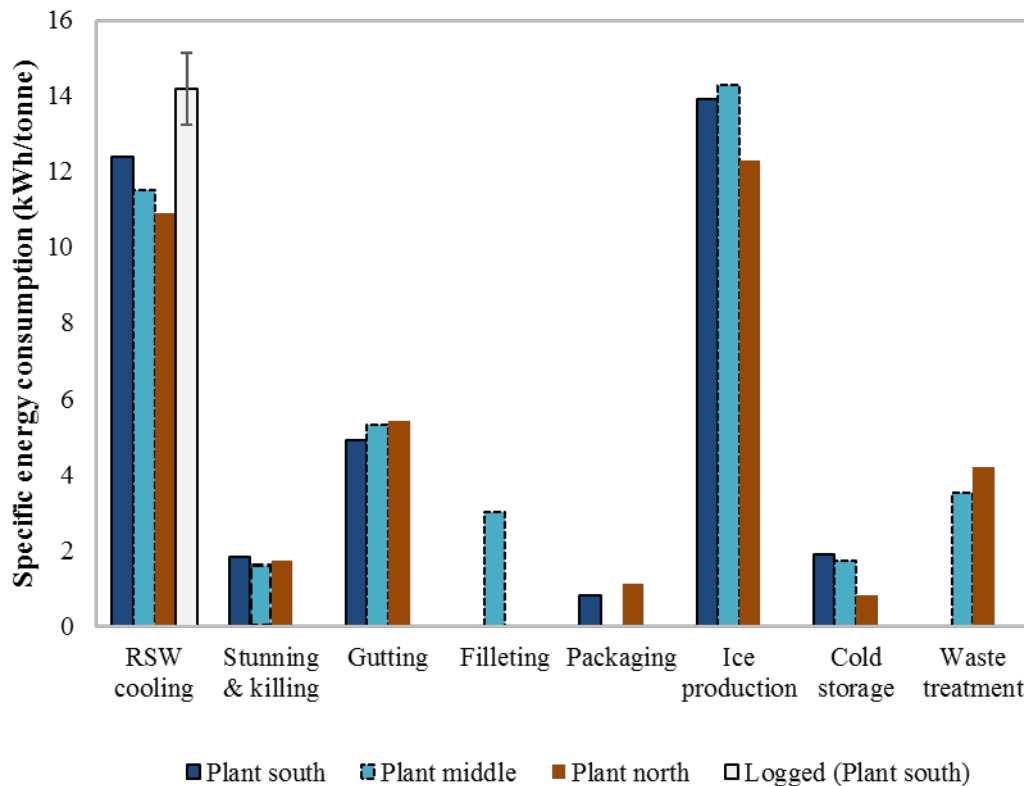


Figure 5. Hourly specific power consumption (kWh/tonne) in main unit operations of salmon plants

¹ Filleting is only performed at Plant *Central*.

² Energy consumption for packaging in Plant *Central* and waste treatment at Plant *North* is not shown.

As a further step, energy consumption for the RSW cooling system in Plant *South* was continuously measured over 5 days in late June, 2015. Calculations based on Eq. 1 gave hourly specific energy consumption of 7.5 (1.1) and 6.7 (0.8) kWh/tonne for the cooling of RSW in bleeding and washing tanks, respectively (Figure 5). Standard deviations are shown in parenthesis ($N = 27579$, $\alpha = 0.05$). The energy data provided by the Plant *South* gave an estimated specific power consumption of 6.8 and 5.6 kWh/tonne for bleeding and washing processes, respectively. Slightly higher values with logged data was apparently due to higher fish/sea temperature during the summer season (June).

3.3 Theoretical heat load calculations

Theoretical heat load from the salmon was calculated based on temperature of fish going into the plant and the end temperature after chilling. The three plants operated with different end temperatures, where Plant *South* had 2 °C, plant *Central* 1.4 °C and plant *North* 1 °C. The results from these calculations are shown in Figure 6. The heat load from the salmon is lowest in March for all three of the plants and highest in August. The average heat loads are similar for *South* and *Central* plant, but lower for the northern plant. When calculating the average heat load with the same end temperature (2°C), the difference in start temperatures are more visible. The southern plant have highest heat load in general and the northern have the lowest.

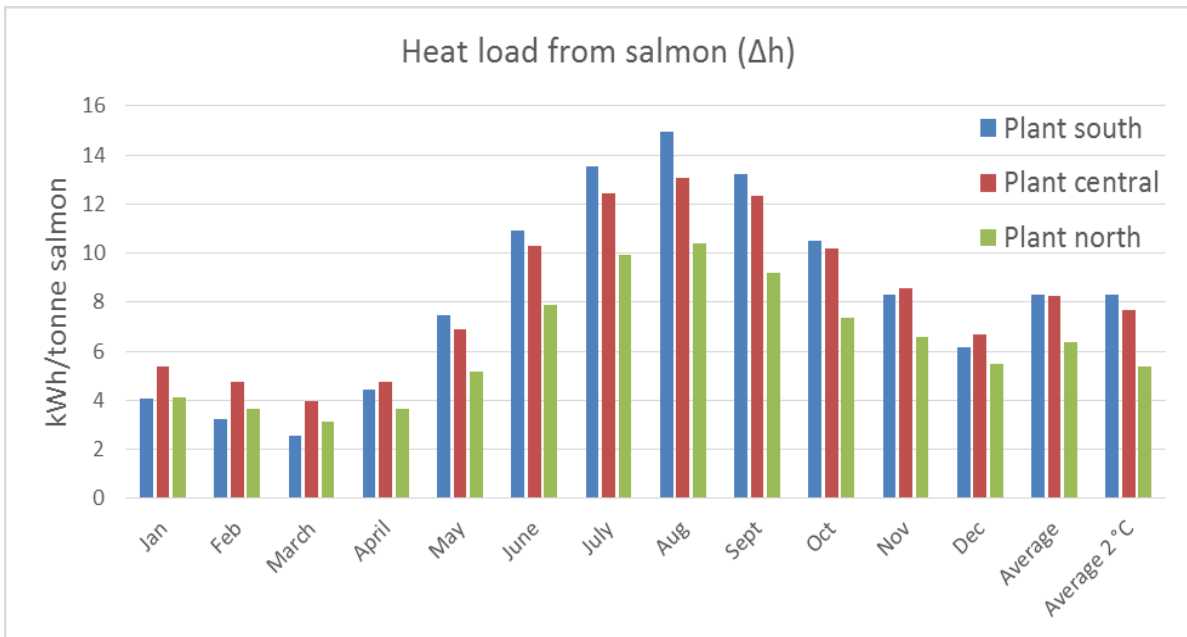


Figure 6. Theoretical heat load from salmon for the different plants and months.

The theoretical heat load calculations and the measured energy consumption at the central plant are compared in Figure 7. The theoretical heat load from the fish is between 4 % and 13 % of measured energy consumption at the entire plant. The resulting energy consumption because of the heat load (of the RSW-system) were not calculated because the coefficient of performance (COP) were not known. However, Figure 7 shows that the start temperature of the fish is not that important for the total energy consumption. 1°C difference in start or end temperature will result in 1 kWh/tonne difference in heat load, which could result in a change in energy consumption of 0.25 % (using a COP of the refrigeration system of about 4) for the average consumption. This is negligible and it can be concluded that other factors than seawater temperature are affecting the energy consumption much more. Another factor that could be more central is the recirculation factor, which says how much of the refrigerated water that is recirculated in the tanks. The size of this has not been investigated yet.

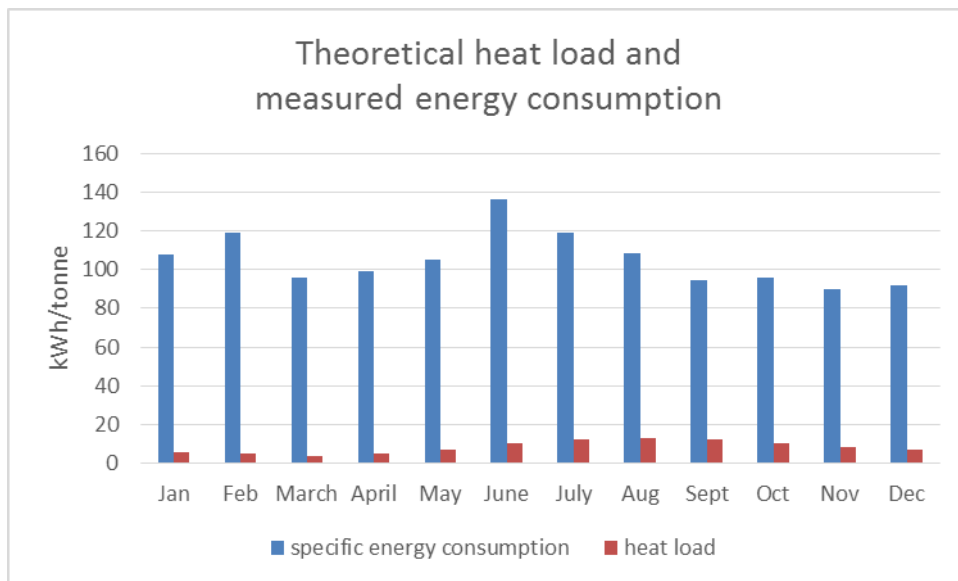


Figure 7. Comparing theoretical heat load and total measured energy consumption. Notice that these are for comparison of the magnitudes only, since the energy consumption for removing the heat load is not calculated.

4. CONCLUSION

Energy consumption was investigated at three different salmon slaughterhouses located in southern, central and northern parts of Norway. The refrigeration systems use ammonia as refrigerant, which is common in food processing industry in Norway. In 2015, the specific energy consumption for these facilities was 105.7, 103.1 and 85.1 kWh/tonne, respectively. This indicated that these facilities consumed less or similar energy than other plants, when compared to the levels observed between 2006 and 2008. The energy consumption in plants showed seasonal variation and the variation was linked to production volumes throughout the year. The variation in seawater temperature did not affect the energy consumption considerably. Another factor that could be more central is the recirculation factor, which says how much of the refrigerated water that is recirculated in the tanks. The distribution of energy consumption among main process steps indicated that 70.7 % of energy consumption was related to chilling and ice production. Energy consumption by different process steps did not vary dramatically with respect to each plant. However, plants located in further north used less energy for chilling processes. Results obtained in this work can be utilized as a benchmark for evaluation of the feasibility of future alternative technologies as well as assessing the environmental impact of the current technology. There is need for even more detailed description in order to see where there most efficient processes are and where there are possibilities for improvement.

5. ACKNOWLEDGEMENTS

The authors thank the Research Council of Norway for their financial support through Grant No. 233689.

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