Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Ocean Operations and Civil Engineering

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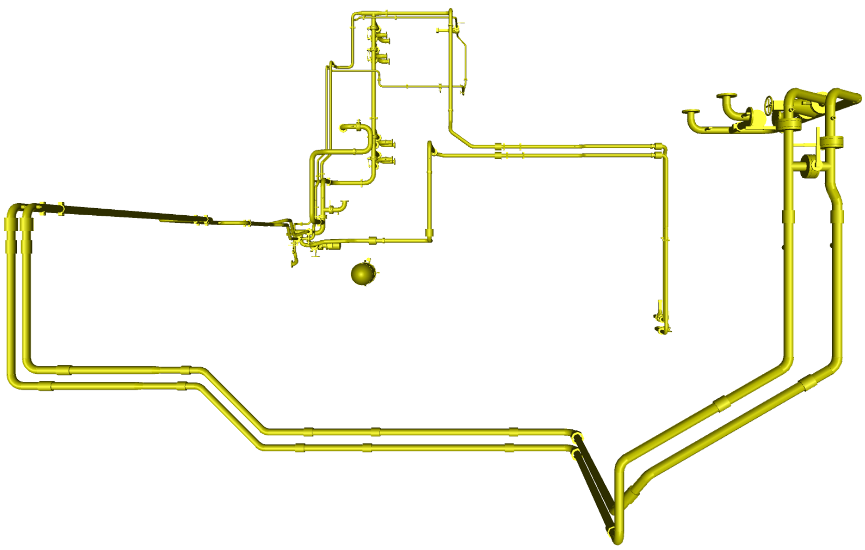
Central Heating System Design
Constant Versus Dynamic Flow

Bachelor's thesis in Product and System Design
Supervisor: Lars Petter Bryne
Co-supervisor: Terje Ottersen & Runar Fiske
May 2023



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VARD
a Fincantieri company

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1 Sammendrag

Sentralvarmesystemet ombord et servicefartøy er et system som henter overskuddsvarme fra motorene samt produserer varme i en oljefyrt kjel og leverer den til ulike forbrukere. I denne oppgaven utforskes potensialet for å energioptimalisere et slikt system ved å bytte fra konstant volumstrøm til et som kan styres dynamisk etter behovet til forbrukerne. I oppgaven er det lagt stor vekt på numeriske beregninger for effekten av volumstrøm, pumpetrykk og frekvensstyring.

Ved å bytte til et dynamisk system er det mulig å spare energi i pumpesystemet, som vil føre til lavere drivstofforbruk og lavere miljøgassutslipp. To forskjellige løsninger har blitt sammenlignet og vurdert. Den første løsningen var å justere volumstrømmen til hver forbruker ved hjelp av dynamiske ventiler, samt å frekvensstyre pumpen slik at pumpekurven treffer systemkurven i det optimale driftspunktet. Den andre løsningen var kun justering av volumstrømmen til hver forbruker uten frekvensstyring av pumpen. Som forventet var det den første løsningen som hadde de største besparelsene basert på utregningene i denne oppgaven.

Til tross for effekten av frekvensstyring var det løsningen med å justere volumstrømmen som ble arbeidet videre med, da denne løsningen også har store besparelser. Dette er et enklere system med få forandringer sammenlignet med det originale systemet. Det ble konkludert med at ved å bytte til systemet ved justering av volumstrøm potensielt kan spare 70 % av energiforbruket til hovedpumpen som tilsvarer rundt 100 000 kr per år i drivstoffkostnader. Denne investeringen har en beregnet avkastning på investering på 2,1 år.

Besvarelsen består av en hovedrapport der teori, metode, resultater og konklusjoner er presentert. Samt nødvendige systemdokumenter som P&ID, abstract of function, systembeskrivelse, armaturliste og brukermanual som er produsert av gruppen. Beregningene gjort i denne oppgaven er også vedlagt.

2 Abstract

The central heating system on board a service operative vessel is a system that extracts excess heat from the engines and produces heat in an oil fired boiler and delivers it to various consumers. This project explores the potential for energy optimization of such a system by switching from constant flow, to a flow that can be dynamically controlled according to the needs of the consumers. The project has great emphasis on numerical calculations for the effects of flow restriction, pump pressure and frequency control.

By switching to a dynamic system, it is possible to save energy in the pumping system, which will lead to lower fuel consumption and lower environmental gas emissions. Two different solutions have been compared and evaluated. The first solution was to adjust the flow to each consumer using dynamic valves, as well as frequency control on the pump so that the pump curve hits the system curve at the optimal operating point. The second solution was only adjusting the flow to each consumer without frequency control of the pump. As expected, it turned out that the first solution had the largest savings based on the calculations in this project.

Despite the effect of frequency control, solution one was developed further, as this solution also has significant savings. This is a simpler solution with few changes compared to the original system, thus bringing the development costs down. It was concluded that switching to this system by adjusting the flow has the potential to save ∼70 % of the energy consumption of the main pump, which corresponds to ∼ 100 000 NOK per year in fuel costs. This investment has a calculated return on investment of 2.1 years.

This submission consists of a main report where theory, methodology, results and conclusions are presented. Necessary system documents such as P&ID, abstract of function, system description, valve list and user manual created by the group are included. The calculations preformed in this project are also attached.

3 Project Description

MASA2900 BACHELOROPPGAVE

Institutt for havromsoperasjoner og byggteknikk

NTNU
Ålesund

Hovedprosjekt

for

Sindre Kildal Haakenstad og Victoria Omholt

Produkt- og systemdesign

Vårsemester 2023

Tittel:

Central Heating System Design

Varmegjenvinning og reduksjon av strømforbruk ombord er avgjørende for å designe Zero Emission skip. Central Heating System er et varmedistribusjonssystem som henter overskuddsvarme fra varmekilder som HT kjølesystem og som distribuerer varmen til ferskvannsproduksjon, tank heating, til air handling uniter til oppvarming av innredning/accommodation ombord. Systemet er i mange fartøy det viktigste varmegjenvinningssystemet og dermed avgjørende å designe best mulig tilpasset hvert enkelt fartøy. Systemet kjøres ofte som et constant flow system der sirkulasjonspumpen(e) kjører kontinuerlig. Systemet kan designes som et dynamisk system for å optimalisere/redusere strømforbruket til systemet. Lite er gjort for å synliggjøre faktisk sparepotensiale ved å endre systemet til dynamisk system.

Kandidatene skal i denne oppgaven:

1. Sette seg godt inn i funksjonene til ett av VARDs SOV vessel central heating system design, og kartlegge forskjellene, fordelene og ulempene ved konstant vs. dynamisk flow system.
2. Basert på det valgte fartøyet foreslå hvordan systemet kan designes for å være mest mulig energi- og kostnadseffektivt. Å tallfeste sparepotensialet (energi, CO_2 og Nox utslipp) er også viktig.
3. Utvikle et konsept (f.eks. regneark eller andre verktøy) for valg av konstant eller dynamisk flow system, som kan brukes som utgangspunkt for diskusjon med rederier om design-prinsipp.
4. I den grad det er tid til det, studere og analysere konsekvensene av å bytte fra tradisjonelt drivstoff til alternative drivstoff som metanol og hydrogen.

Veileder ved NTNU i Ålesund er Lars P. Bryne, og kontaktpersoner/ faglig veiledere ved Vard AS er Terje Ottersen og Runar Fiske.

Besvarelsen redigeres som en teknisk rapport, med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse etc. Ved utarbeidelsen av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelsen legges det stor vekt på at resultatene er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte og diskuteres utførlig.

4 Preface

It would not have been possible to complete this project without contributions from several people. A huge thank you to Lars Petter Bryne our supervisor at NTNU for both this project and through our bachelor education. The whole machinery department at Vard Design & Engineering should be acknowledged for answering questions and letting us use the offices during this time. We would like to especially thank Andreas Vartdal for his guidance throughout the process. The yard visit to Søvika on a similar vessel was very helpful for our understanding of the system.

Additionally, we would like to express our gratitude to Frese for their guidance and introduction to pressure independent valves for our system. Allweiler also deserves a thank you for arranging a crash course in pump theory.

Contents

5 Table of Symbols

Symbol	Description	Units
$\frac{dU}{dt}$	Rate of change in internal energy	W
k	Combined heat loss coefficient	$W/m^2 \cdot K$
A_O	Outside area of the pipe	m^2
T	Temperature	Celsius
r	Radius	m
d	Diameter	m
h	Convection coefficient of fluid/gas	$W/m^2 \cdot k$
λ	Conduction coefficient of material	$W/m \cdot k$
Q	Volume flow	m^3/h
k_v	Flow coefficient	m^3/h
k_{vs}	Flow coefficient with a valve at a given position	m^3/h
SG	Specific gravity	1
p	Pressure	bar = 10^5 Pa
H	Pressure (Head of water column)	m = 0.098bar
q	Heat	W
ρ	Density	kg/m^3
μ	Dynamic viscosity	$Pa \cdot s$
f	Frequency	Hz
C	Change in frequency	1
η	Efficiency	1
$H(Q)$	Head as a function of the flow	m = 0.098bar
$H(Q,C)$	Head as a function of the flow and change in frequency	m = 0.098bar
$\eta(Q)$	Efficiency as a function of the flow	1
V	Volume	m^3
m	Mass	kg

6 Introduction

In the past few years, there has been a drastic shift towards moving to greener energy solutions and energy optimization, this is now also affecting the maritime industry. In this project, the possibility of energy optimizing a central heating system onboard a service operative vessel will therefore be explored. The specific vessel and associated shipping company cannot be revealed because of competitive advantages, however, the vessel is used for maintenance on offshore wind farms. By optimizing the central heating system, it is not only possible to lower the carbon footprint of the vessel, but this could also have a large economic advantage as a result of lower fuel consumption. These advantages will probably also be more evident in the future with stronger regulations in greenhouse gas emissions and higher fuel prices.

The system that is in use today mainly uses excess heat from the engines to provide heat to various consumers on the vessel. This is excess heat that would otherwise be wasted to the environment. The main issue in the pumping system, as of now, is the central heating pumps. The pumps are set to have a constant flow to deliver heat to each consumer. To control the distributed heat, there are mainly two solutions in place. Bypassing the consumer with a temperature-controlled three-way valves, or closing the flow to a consumer with a manual valve. This is wasteful since the pumps would have to deliver an unnecessary amount of flow even when the demand for heat is low, which leads to increased power consumption, higher fuel consumption, and greenhouse gas emissions. There is a possibility to optimize the system by designing a system that uses dynamic flow to deliver what's necessary to each consumer.

This project is a collaboration with Vard Design & Engineering. Vard is a ship-building company with headquarters located in Ålesund along with shipyards in Sunnmøre and several other places in the world. Vard provides engineering and high-end design services to the global maritime industry.

7 Understanding the System

This central heating system is on board a Service Operative Vessel, also known as a SOV. It is a heat-exchanging system that uses excess heat from the four engines and an external oil-fired hot water boiler to deliver heat to seven different consumers in the system. As of now, the system is utilizing a constant flow system to deliver heat around the piping system, which is optimized for a steady-state condition, where all the consumers are in use. This configuration is not ideal during most working conditions, which can lead to increased pressure, flow and power consumption from the pumps if not adjusted. This can be prevented by frequency control of the pump to decrease the flow, however the flow in the system would also have to be controlled by throttling to ensure the flow to each consumer as desired.

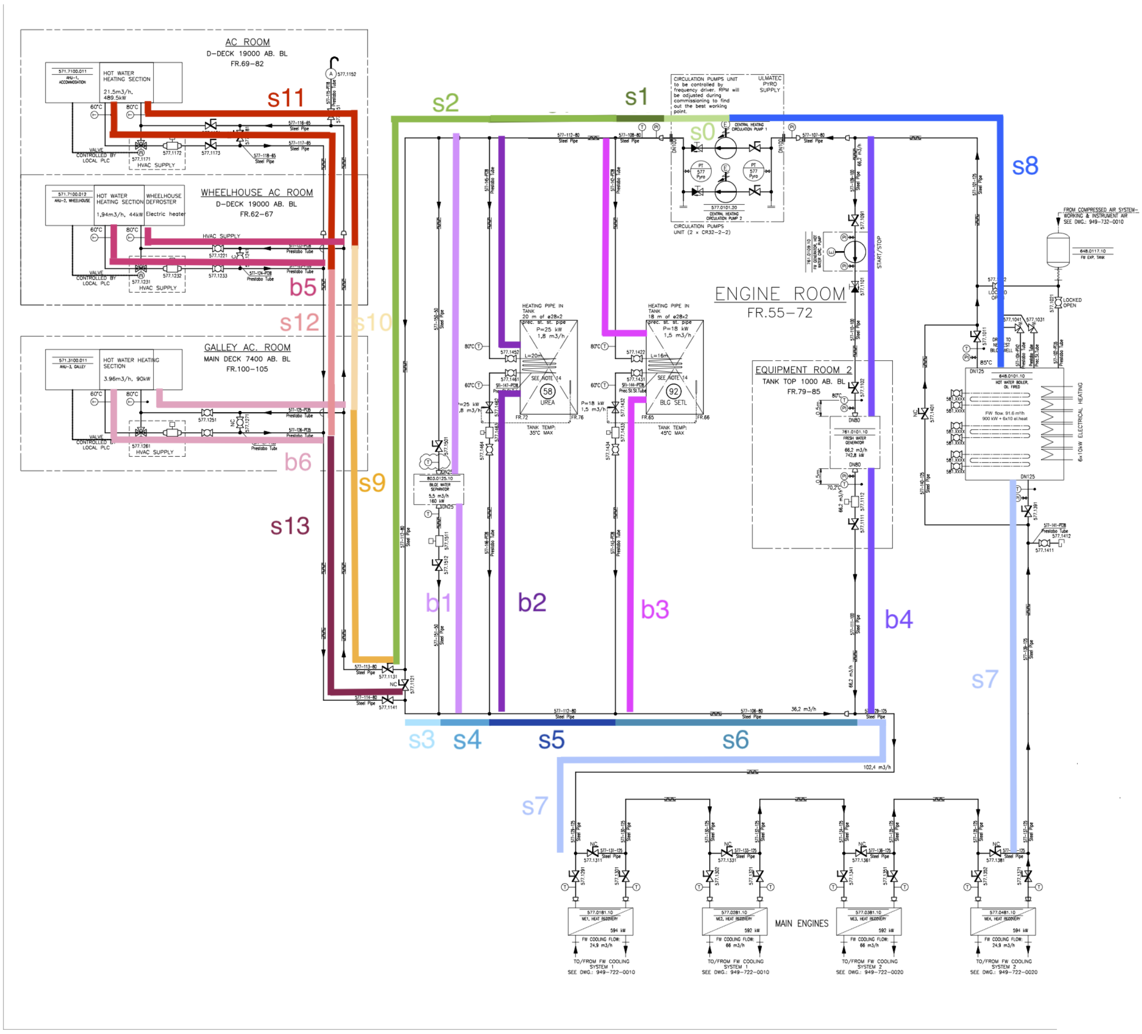


Figure 7.1: P&ID of the central heating system

7.1 Sections and Branching

To have a better overview and control of the central heating system, it was decided to divide the system into a main piping system with branches and then divide them further into sections. The pipeline from the main pump through air handling unit one, the heat recovery system and the oil-fired boiler was chosen as the main pipeline. This is because the majority of the flow delivered from the central heating pump takes this path. The division of the sections is done between pipes with different flows, pipe diameters, or wherever it is natural to divide the sections. The details of the section and branching system are illustrated in figure 7.1.

7.2 Heat Recovery Units

The heat recovery system extracts excess heat from the jacket water of the engines by going through a closed heat recovery unit. The heat recovery units from the four engines are connected in series. Two of them are designed to receive a maximum of 592 kW of heat, while the other two will receive a maximum of 594 kW of heat, this is when the engines are running at full capacity. This configuration has some limitations, firstly the heat exchange is proportional to the difference in temperature between the jacket water from the engines and the fluid in the heating system. Since the heat recovery system is connected in series, the temperature of the central heating fluid will increase as it travels through each heat recovery system, this makes each recovery system less effective.

The heat recovery system could theoretically be improved by connecting the units in parallel, which will increase the temperature difference between the liquid from the central heating system and the coolant from the engines. This configuration has a fatal flaw. If any of the units are shut off, the unit would have to be bypassed, thus making the heat recovery significantly less efficient. Vard is therefore now using the series configuration as a standard. This is also partly because when the engines are running, there is usually more than enough heat coming from the engines, to heat the fluid in the central heating system.

7.3 Pumping System

The central heating system has three pumps, where there are two main pumps and one pump to deliver flow to the freshwater evaporator. These would have to maintain the desired flow and pressure difference, in addition to overcoming the pressure drop from friction, bends, contractions, enlargers, and valves. These pumps have frequency control, but in this case, the frequency is set to the maximal operating point, meaning that the frequency is adjusted so that the pump curve intersects the system curve when all the consumers are in use.

The two main pumps are Grundfos CR32 centrifugal pumps as shown in figure 7.2 and are connected in parallel. Pumps connected in parallel is illustrated in figure 7.3. During normal conditions, only one of the main pumps is in use, and the second one is used as a backup pump in case of failure. In these conditions, the active pump delivers a flow of 36.2 m^3/h with a differential pressure of around 3 bar, depending on the working conditions. The pump that is in use is alternated between the two main pumps, in order to distribute the wear between the pumps.

Figure 7.2: Grundfos C32 Centrifugal Pump

[1]

Figure 7.3: Main pumps connected in parallel on another SOV

This system has dedicated a pump to deliver water to the freshwater evaporator. It is an Allweiler centrifugal pump and is set to deliver a flow of 66.2 m^3/h. The reason this branch has a separate pump is likely to minimize the working range of the main pump. If this branch is closed, this would not significantly affect the central heating pump.

7.4 The Pipes

The central heating system contains both different sizes and sort of pipes. Most of the pipes in this system are DN80. These are mainly steel pipes but with some Prestabo tubes, which are pipes consisting of exterior galvanized steel, that makes them more suitable for exposure to high temperatures.

7.4.1 Heat Loss in the Piping System

To determine the heat required from the heat recovery system and the oil-fired boiler, the heat loss in the pipes has to be calculated. This was done by considering the heat transfer for each section with the following formula 7.1 and 7.2 [2].

$$q_{loss} = \frac{dU}{dt} = \sum k \cdot A_O \cdot (T_i - T_o) \tag{7.1}$$

Where k can be found with the formula for the overall heat transfer coefficient for round pipes with insulation. The thickness of the steel pipes, and of the insulation, are standardized by Vard and can be found in their Pipe Insulation Standard [3]. The values for calculation is illustrated in figure 7.4

$$k = \frac{1}{\frac{r_2}{r_0 \cdot h_i} + \frac{r_2 \cdot \ln \frac{r_1}{r_0}}{\lambda_1} + \frac{r_2 \cdot \ln \frac{r_2}{r_1}}{\lambda_2} + \frac{1}{h_o}} \tag{7.2}$$

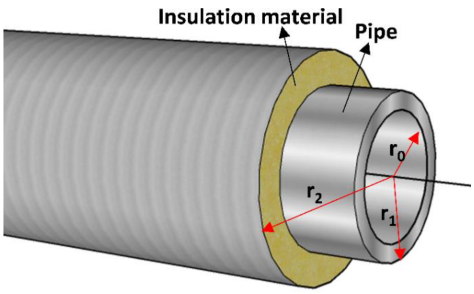


Figure 7.4: Illustration of the constants for calculating the heat-loss in a pipe [4].

By assigning a value of $k \cdot A_o$ to each section, it would be possible to calculate the heat loss to the cold and hot fluid sides. This was done with a simplification that the temperature of the fluid is constant for the hot and cold sides, even if the fluid is losing thermal energy along the path. This is a good enough assumption since this value would have such a large uncertainty, and calculating an accurate heat loss value would be too comprehensive for this project. The heat loss was therefore calculated with a constant fluid temperature of 60 $°C$ and 80 $°C$ for the cold and hot sides respectively and a constant outside temperature of 15 $°C$. That yields the following formula for the heat loss in the pipes.

$$q_{loss} = \frac{dU}{dt} = \Delta T_{hot} \sum_{hot} k \cdot A_O + \Delta T_{cold} \sum_{cold} k \cdot A_O \tag{7.3}$$

These values were calculated using the Excel sheet shown in attachment A.6. A summary of the heat-loss in each branch can be found in table 7.1. This gave a total heat loss in the pipes of 4.96 kW at the given conditions.

	Ao $\cdot k[w/k]$	Outside temperature [°C]	Delta T [K]	Heat loss [W]
Main pipeline				
Cold side	15.53	15	45	699
Hot side	23.78	15	65	1546
Branch 1				
Cold side	1.55	15	45	70
Hot side	4.88	15	65	317
Branch 2				
Cold side	1.56	15	45	70
Hot side	1.56	15	65	101
Branch 3				
Cold side	1.34	15	45	60
Hot side	1.34	15	65	87
Branch 4				
Cold side	10.71	15	45	482
Hot side	9.28	15	65	603
AHU 2				
Cold side	3.90	15	45	176
Hot side	3.90	15	65	254
AHU 3				
Cold side	4.47	15	45	201
Hot side	4.47	15	65	290

Table 7.1: Heat loss in branches and sections

7.5 Central Heating Fluid

The fluid in the Central Heating System is a mixture of water and 6% cooltreat AL, which is an organic corrosion inhibitor. This prevents corrosion in the pipes. The reason this fluid is used instead of other liquids with better thermodynamic properties is likely because of the non-toxicity of this water mixture and also the cost efficiency.

In terms of mechanical properties, they were considered the same as freshwater. Since the concentration of Cooltreat AL is so low, it would not affect the properties significantly. The parameters for this fluid are therefore chosen as follows: density $\rho = 998.2kg/m^3$, dynamic viscosity $\mu = 1.0016 \cdot 10^{-3} \cdot Pa \cdot s$, and specific gravity $(SG) = 1$.

7.6 The Consumers

This central heating system has seven consumers. These are essentially where the system delivers its heat. All the consumers are connected in parallel, which is optimal for the same reason as with the heat recovery system. By connecting them in parallel, the system will be able to deliver the most heat, because of the temperature difference between the fluid and the environment.

7.6.1 Accommodation - AHU1

The majority of the flow from the main pumping system is used for accommodation. This is hereby referred to as Air Handling Unit One (AHU1). AHU1 is set to receive 21.5 m^3/h of flow and 489,5 kW of heat during maximum working conditions. AHU1 is set to deliver heat at full capacity when the outside temperature is at -20°C, and it is set to shut off at temperatures above 12 °C. This is the main air handling unit, and it delivers heat to the majority of the environment onboard. This unit is located at the D-Deck, which means that it is located with an elevation of 15.4 m above the main pumps. This is the consumer with the highest elevation, meaning that the differential pressure over this consumer will probably be low.

7.6.2 Wheelhouse - AHU2

The wheelhouse Air Handling Unit, hereby referred to as AHU2 is connected in parallel as a branch in the main piping system. It is set to receive a flow of 1.94 m^3/h and deliver 44 kW of heat during maximum working conditions. AHU2 works at maximum capacity when the outside temperature is at -20 °C, and it shuts off at 20 °C. AHU2 delivers heat to the wheelhouse. This AHU is separate from the rest of the system, likely because this makes it possible to control the air conditioning in the wheelhouse separate from the rest of the system, as well as defogging on the windshields. During extreme conditions, it would also be possible to run the air conditioning in the wheelhouse, without the rest of the system. This AHU is also located on the D-deck, which means that it has an elevation of 15.4 m similar to AHU1.

7.6.3 Galley - AHU3

The Galley Air Handling Unit, hereby referred to as AHU3, is also connected in parallel to the main piping system, similar to AHU2. It is set to receive a flow of 3.96 m^3/h, and deliver a heat of 90 kW at the maximum working point. AHU3 runs at full capacity when the outside temperature is at 20 °C and shuts off when the outside temperature is 12 °C. The purpose of AHU3 is to deliver heat to the galley, and it works with the same temperature conditions as the AHU1.

7.6.4 Bilge Water Separator

Bilge Water Separator, hereby referred to as BWS, is connected as a branch to the main pipe system. It is set to receive a flow of 5.5 m^3/h. A BWS separates oil and water mixtures. AlfaLaval is the supplier of this BWS and the model is called PureBilge. This is a fully automated centrifugal oily water separation system that cleans oily water onboard vessels at sea [5]. It makes oily water safe for discharge overboard by effectively removing marine oil pollution. In order to meet international regulations for release into the sea, it is important that bilge water is treated to reduce oil content levels [**PureBilage**]. This BWS is approved by International Maritime Organization (IMO).

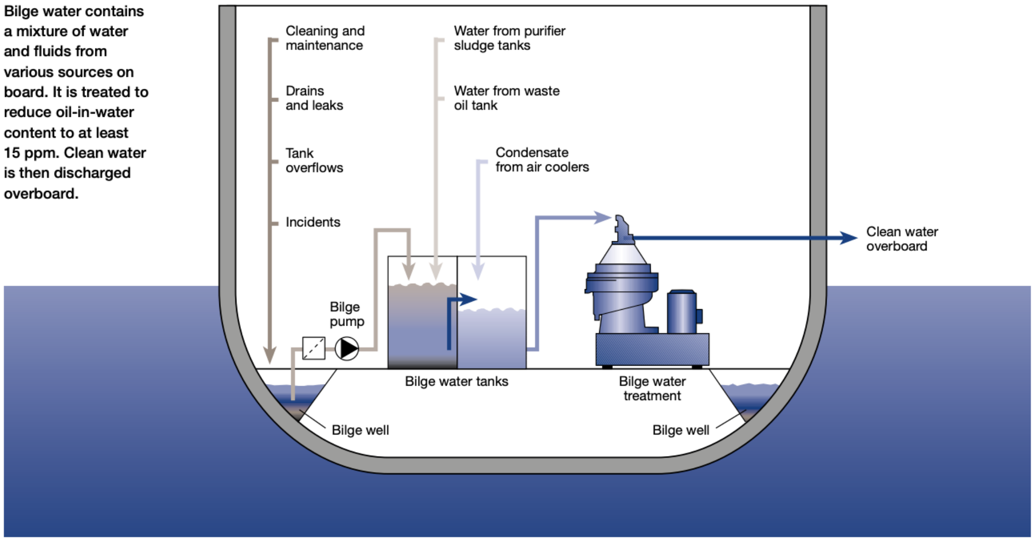


Figure 7.5: Illustration of Bilge Water Separator [6]

7.6.5 Urea Tank

Urea is a usual chemical commodity used in different products. In this case, urea is used to reduce Nitrogen Oxides (NO_X) emissions from vessels. Normally, NO_X reduction urea is delivered as a pre-mixed solution with 60 % deionized water and 40 % of urea. The urea tank is regulated by a self-acting temperature control valve.

7.6.6 Bilge Settling Tank

A deep tank in the engine room is used to pre-clean fuel oils by gravity. A liquid mixture in the settling tank clears slowly as a heavier liquid and solids sink to the bottom under the influence of gravity.

7.6.7 Freshwater Evaporator

The freshwater evaporator is the most demanding consumer in the system. This component is designed to have a flow of 66.3 m^3/h from the central heating, and it requires an external pump to deliver the required flow. During full operation the evaporator has a capacity of producing 25.1 m^3 of fresh water per day The evaporator is an Aqua Blue C100-HW86-108 freshwater generator from AlfaLava. The freshwater generator works by lowering the pressure of seawater while being heated by the central heating system. The seawater then undergoes partial evaporation, which will generate a mixture of vapor and brine. This mixture is then separated, which will generate a vapor from freshwater. This vapor is then cooled, which condenses the vapor. The fresh water is then mineralized and then transported to a fresh water tank, where it is now drinkable. [7].

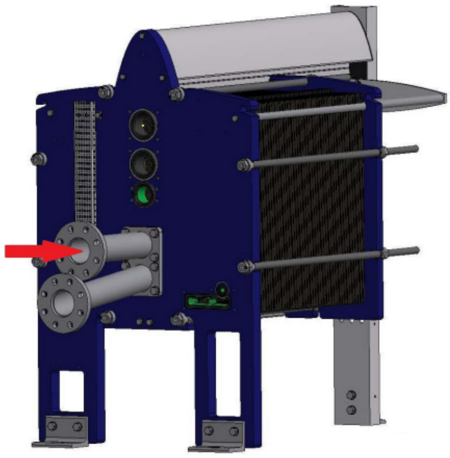
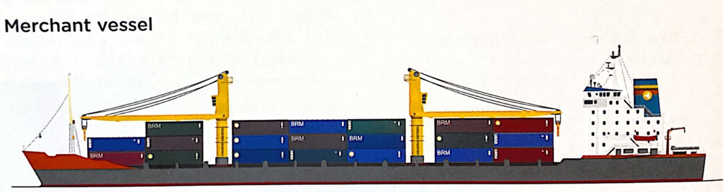


Figure 7.6: Aqua Blue C100-HW86-108 freshwater generator from AlfaLaval

The vessel has two methods for producing fresh water: a reverse osmosis system, and evaporation using heat from the central heating system to evaporate fresh water. The reverse osmosis system is not using heat from the central heating system, however, the water that is generated is of lesser quality than water produced with evaporation. It is therefore safe to assume that the water that is meant for human consumption is produced in the evaporator, and the water used for technical purposes is produced using the reverse osmosis method. By using experience values from Marinfloc on freshwater consumption for service vessels, it is possible to estimate the runtime for the freshwater generator.

Specification	**Value**
Capacity m^3/day	25.1
Demand $m^3/person/day$	0.195
Personel	89
Total demand per day m^2/day	17.355
Runtime %	69 %
Runtime h, min/day	~16h, 30min

Table 7.2: Values for freshwater generation for service vessels [8].



Waste stream	Volume [l/person/day]	BOD5 [mg/l]	TSS [mg/l]	Total BOD(5) [mg/person/day]	Total TSS [mg/person/day]
Accommodation grey water	110	200	100	22000	11000
Laundry grey water	35	300	300	10500	10500
Galley grey water	35	2000	2500	70000	87500
Black Water (Vacuum)	15	3000	1500	45000	22500
Sum	195	-	-	147500	131500
Average per liter (mg/l)	-	-	-	756	674

Figure 7.7: Daily water production

7.7 Calculating Pressure Drop

In order to determine losses in the existing system, the pressure drops the pumps would have to overcome has to be calculated. The pressure drops were mainly calculated using SF Pressure Drop software made by Rolls-Royce. However, some calculations had to be done manually or were found in product specifications from the suppliers. The results of the pressure calculations can be found in the pressure calculation attachment. The pump would have to be dimensioned to overcome the path that offers the most severe pressure drop, which in this case is the path through AHU1. This can be found in the calculation summary in the attachment A.7. The column comparison compares the results from the pressure calculation to find the path that offers the largest pressure drop, as shown in figure 7.8

Branch	Cumulative Pressure drop (bar)	Flow m3/h
Main Pipeline	2.88	21.5
Branch 1	0.13	5.5
Branch 2	0.61	1.8
Branch 3	0.29	1.5
Branch 4	1.51	66.2
Branch 5	0.94	1.94
Branch 6	0.60	3.96

One or more of the Nodes has a more severe Pressure drop than the main pipeline

Column Comparison

Branch 1	
Inlet Column	6
Outlet Column	40
Pressure through main pipe (bar)	1.35
Pressure through branching pipe (bar)	0.13
Pressure through the main pipe has the most severe pressure drop	

Branch 2	
Inlet Column	6
Outlet Column	44
Pressure through main pipe (bar)	1.40
Pressure through branching pipe (bar)	0.61
Pressure through the main pipe has the most severe pressure drop	

Branch 3	
Inlet Column	6
Outlet Column	46
Pressure through main pipe (bar)	1.41
Pressure through branching pipe (bar)	0.29
Pressure through the main pipe has the most severe pressure drop	

Branch 4		
Inlet Column	62	
Outlet Column	48	Caution, outlet node is before inlet node
Pressure through main pipe (bar)	1.50	
Pressure through branching pipe (bar)	1.51	
Pressure through the branching pipe has the most severe pressure drop		

Branch 5	
Inlet Column	16
Outlet Column	30
Pressure through main pipe (bar)	1.13
Pressure through branching pipe (bar)	0.94
Pressure through the main pipe has the most severe pressure drop	

Branch 6	
Inlet Column	14
Outlet Column	33
Pressure through main pipe (bar)	1.18
Pressure through branching pipe (bar)	0.60
Pressure through the main pipe has the most severe pressure drop	

Figure 7.8: Pressure drop overview

7.7.1 Roughness, Bends, and Reducers

The SF Pressure Drop software was used to calculate the pressure drop caused by the roughness of the pipes, the bends in the pipes, and changes in pipe diameter.

To determine the necessary parameters for SF Pressure Drop, the 3D-model of the piping system was analyzed in Navisworks Freedom 2023. The parameters that had to be determined in the 3D-model were: the lengths of each piping section, the bending angle in each bend and the angle of each contraction/enlargement. These were measured using the measuring tool in Navisworks. This method of determining these parameters is not entirely accurate, however, because of the significant uncertainty of such a calculation. The result of the pressure calculation would have to be cross-checked with real data, regardless of the accuracy of the calculations.

The roughness of the pipes was chosen to be 0.2 mm, which is referred to as "Steel after long operation cleaned" in SF Pressure Drop's pipe library. The prestabo tubes have a roughness of 0.15 mm, according to Viegea, the supplier. The bending radius of all bends was set to be 1.5 times the internal diameter of the pipes ($r_{bending} = 1.5 \cdot d_{Pipe}$), which is specified in the P&ID.
A.2

7.8 Valves

During normal working conditions, the system runs through several valves. These valves also cause some pressure drop, even if they are fully open.

7.8.1 Butterfly Valve

The valves can be found in sections 7, 8, 9, 12, and 15, and branches 1, 2, 3, and 4 as well as the AHU branches. The valves are manually operated butterfly valves from Brødrene Dahl. These valves have a relatively large pressure drop due to the closing mechanism shown in figure 7.9. To calculate the pressure drop in these valves, the supplier was contacted, and they were able to provide a table of K_v values. The K_v value is found experimentally by testing which flow gives a pressure drop of one bar.

Figure 7.9: Lug butterfly valve [9].

The K_v values can be found in figure 7.10. As shown, this value has units m^3/h at 1 bar. If we assume that the increase in pressure is proportional to the square of the fluid flow, the pressure can be calculated by the formula 7.4. SG was set to 1, which is the specific gravity of water.

GALA Regulating Systems

Kv Values-Valve Sizing Coefficients （m^3/h@1bar) DN50 to DN1500

Size mm	10°	20°	30°	40°	50°	60°	70°	80°	90° Full Open
50	0.1	4.3	10.3	20.6	38.6	54.8	77.1	107.1	115.7
65	0.2	6.9	17.1	31.7	55.7	84.0	123.4	174.8	188.5
80	0.3	10.3	18.9	33.4	60.0	99.4	156.8	235.6	258.8
100	0.4	14.6	30.8	66.8	119.1	197.1	311.9	467.9	514.1
125	0.7	24.9	52.3	114.0	203.1	335.9	531.3	796.9	875.7
150	1.7	38.6	81.4	175.7	313.6	518.4	820.9	1231.4	1353.0
200	2.6	76.3	161.1	349.6	623.0	1030.0	1630.7	2445.6	2687.2
250	3.4	129.4	274.2	594.7	1060.0	1754.1	2776.3	4163.7	4575.8
300	4.3	200.5	424.2	918.6	1637.5	2709.5	4288.8	6432.7	7069.4
350	5.1	289.6	612.7	1327.3	2365.9	3914.3	6195.4	9292.2	10211.7
400	6.9	397.6	842.3	1825.2	3253.6	5383.0	8519.3	12778.9	14042.8
450	9.4	527.0	1115.7	2418.2	4308.5	7129.4	11283.6	16925.4	18599.0
500	12.0	677.8	1434.4	3108.8	5539.8	9167.1	14508.1	21761.8	23914.3
600	18.9	1047.1	2216.8	4802.9	8559.6	14162.8	22413.9	33621.3	36946.0
700	30.8	1553.6	3118.3	5686.4	8569.0	12809.8	19510.7	29904.0	42416.5
800	38.6	2045.4	4105.4	7485.9	11814.9	17663.2	26902.3	41231.4	58483.3
900	51.4	2588.7	5195.4	9473.0	14952.0	22353.0	34045.4	52180.8	74014.6
1000	72.0	3584.4	7193.7	13116.5	20701.8	30990.6	47201.4	72343.6	102613.5
1050	299.9	3509.0	7746.4	14659.8	23264.8	37395.0	60411.3	91593.8	100685.5
1200	389.9	4597.3	10145.7	19194.5	26221.1	43873.2	79091.7	119965.7	131962.3
1500	681.8	8076.9	17577.4	33851.1	45187.3	78391.5	136920.4	206191.1	228872.1

Kv=(1/1.167)*Cv

Figure 7.10: k_v values of butterfly valves provided by Brødrene Dahl

$$\Delta p = (\frac{Q}{K_v})^2 \cdot SG \tag{7.4}$$

7.8.2 Check Valve

In this system, there is one check valve, also called a non-return closable valve. The valve is placed after the freshwater circulation pump. A check valve lets the flow go one way, but if the flow reverses, the valve will close to protect the freshwater circulation pump.

Figure 7.11: Non-return closable valve

[10]

7.8.3 Dynamic Regulating Valve

This system also has a number of dynamic valves. These valves are type Frese Sigma Compact and can be found in every branch of the system. These valves have a piston that automatically adjusts so that the flow is constant, given by a pre-setting on the valve, as long as the pressure difference is within the specified range. If the pressure difference is not within the range, the valve will either be fully open or closed and cannot control the flow, in this case, the valve will not serve its purpose. The system curve for a system using these valves is shown illustratively in figure 7.12. This means that the central heating pump would have to overcome the pressure drop from the lower value in the range. The pumps should ideally deliver a pressure difference slightly above, but close to the lower bound. This is because a greater pressure difference in the valve would result in throttling of the system, and the pumps would have an unnecessarily high power consumption.

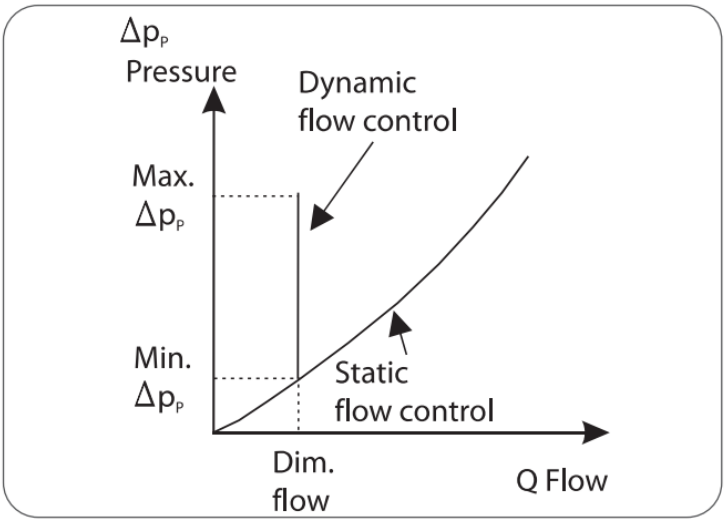


Figure 7.12: Illustration of a system curve using a dynamic regulating valve

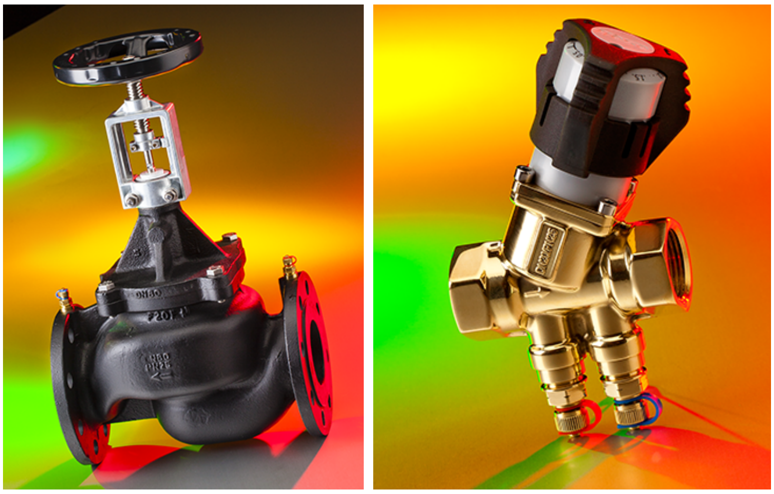


Figure 7.13: Frese Sigma Compact flanged dynamic valve & Frese Sigma Compact dynamic valve with pre-set

[11][12]

7.8.4 Ball Valve

This central heating system is also using ball valves for pipes with a nominal diameter of 30 mm or below. The inner workings of this mechanism are shown in figure 7.14, and it works by turning a hollow ball to limit the flow. During normal working conditions, these valves are either fully open or fully closed. Because there is nothing restricting the flow when the valve is fully open, and when the valve is closed there is no flow. There is effectively no drop in pressure from these valves.

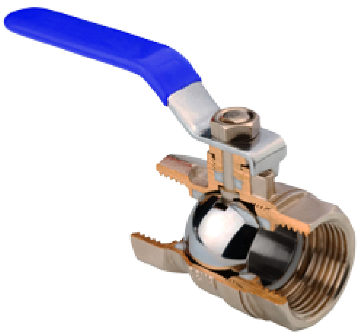


Figure 7.14: Ball valve mechanism [13]

7.8.5 Self-Acting Temperature Control Valve

This system includes two self-acting temperature control valves. The type is Danfoss AVTB, and it is a direct-acting thermostatic temperature controller used to regulate the water temperature in a variety of applications. The valve closes at a rising temperature. These two valves are placed on the urea tank and bilge settling tank. By using these kinds of valves it may reduce heat loss, which in turn may reduce fuel consumption and CO_2 emissions, considering the energy efficiency.

Figure 7.15: Self-acting control valve[14]

7.8.6 Three-Way Motor Operated Valve

The branches connecting the air handling units to the main system also have three-way motor-operated valves. These valves are of the type Oventrop three-way regulating valves. These valves have a sensor connected to their respective air handling unit, and their purpose is to regulate the flow through the AHUs by bypassing the fluid in parallel such that the flow through the heat exchanger is as desired. Their pressure drop can be calculated by the k_{vs}-value which is specified in figure 7.17. These valves are essentially what control the heating of the AHU's since they are the only active components that control the flow to these consumers. The pressure drop and flow from the central heating pump would be determined by the intersection between the system curve and the pump curve. This is what makes the exciting system so inefficient. Since the valve bypasses the excess flow, the central heating pump would have to deliver more flow than necessary, which also results in a higher pressure drop, which raises power consumption.

Figure 7.16: Oventropp 3-way valve

Tekniske data					
NRF	Varenummer	DN	k_{vs}-verdi	Δp_{max} stengetrykk I kPa for 2-veis og shuntventil	Δp_{max} stengetrykk I kPa for fordelerventil
N/A	311130875	15	1,0	1210	600
N/A	311130865	15	1,6	1210	600
N/A	311130845	15	2,5	1210	600
N/A	311130866	20	4,0	920	450
N/A	311130846	20	6,3	920	450
N/A	311130847	25	10,0	500	250
N/A	311130848	32	16,0	350	170
N/A	311130849	40	25,0	150	70
N/A	311130850	50	35,0	70	30
N/A	311130851	65	63,0	560	280
N/A	311130852	80	100,0	360	180
N/A	311130853	100	160,0	220	1100
N/A	311130854	125	220,0	130	600
N/A	311130855	150	320,0	80	400

Figure 7.17: k_{vs}-values for Oventrop three-way valves

7.9 Heat Versus Flow Relation

The heat distributed to each unit is governed by the change in internal energy of the fluid, this can be calculated using formula 7.5. If we assume the temperature difference through the unit is a constant $20°C$ the only variable would be the flow Q. The results from this formula are similar to the specified value in the system drawing. This shows that the delivered heat is proportional to the flow through a consumer, as long as the fluid reaches the necessary temperature difference 7.6.

$$q = \frac{dU}{dt} = C_p \cdot \rho \cdot Q \cdot \Delta T \tag{7.5}$$

$$q \propto Q \tag{7.6}$$

7.10 The Three Modes

In order to optimize the central heating system, it is important to find the optimal pump. Based on three selected modes, harbor mode, transit mode and dynamic positioning mode, it is possible to determine the amount of heat distributed to each unit and the required flow. With these results, it is possible to find the amount of heat that is required, the flow through the central heating pump and the pressure drop that the pump has to overcome. The number of hours in each mode depends on where the vessel will be operating and the weather conditions.

Harbor Mode
When the vessel is docked, the central heating system is in harbor mode.

Transit Mode
When the vessel is in transit from port to a mission, the central heating system is in transit mode.

Dynamic Positioning Mode
When the vessel is on a maintenance mission, the offshore gangway is in operation, and the central heating system is in dynamic positioning mode. In this mode, the vessel uses side thrusters to stabilize with as little movement as possible, to ensure the safety of the maintenance personnel.

7.10.1 Active Consumers

Because the bilge water separator requires momentum when in use, it is only used in transit mode. As for the settling tank, this is only heated before the bilge water separator and is also used in transit mode. However, these consumers are not frequently used. After contacting the shipping company, it turned out that the BWS is in use for approximately between two and three hours per month. The bilge settling tank is in use for approximately 48 hours per month. As for urea, heating is not in use. Since these consumers are so infrequently in use, it does not make sense to optimize the system for their use. A summary of active consumers in each mode can be found in table 7.4.

In all three modes, the AHUs are usually active. The capacity they are running on is dependent on the weather conditions. The freshwater evaporator runs whenever there is a demand for freshwater, and there is enough heat that can be extracted from the engines.

7.10.2 Distribution Spent in Each Mode

To estimate the distribution between the time the vessel would be in each mode, data from a similar vessel owned by the same shipping company was used. The shipping company estimated that this vessel would go to shore approximately every 14 days and spend 15 % of its operating time at harbor. The vessel spends approximately between five and six hours in transit each way to the wind field, making it 10–12 hours per 14 days. The rest of the time would be spent in dynamic positioning mode. Details in the time distribution spent in each mode can be found in the table 7.3.

	Harbor	**Transit**	**Dynamic positioning**
Distribution	15 %	3.5 %	81.5 %

Table 7.3: Hourly distribution in each mode

Active Consumers	**Harbor**	**Transit**	**Dynamic Positioning**
AHU1	Usually active	Usually active	Usually active
AHU2	Usually active	Usually active	Usually active
AHU3	Usually active	Usually active	Usually active
Freshwater Evaporator	Not avtive	Usually active	Usually active
Bilage Water Separator	Usually not active	Usually not active	Usually not active
Bilage Setling Tank	Usually not active	Usually not active	Usually not active
Urea Tank	Usually not active	Usually not active	Usually not active

Table 7.4: The consumers and when they are active in each mode

8 Optimization of the System

With a thorough understanding of how the existing central heating system works, it is possible to discuss how the system can be designed to improve its efficiency. The following section provides information on solutions to improve the system, as well as assumptions that were made to compare the results of different solutions.

8.1 System and Pump Characteristics

Pump Curve

A pump curve is a graphic representation of the performance of a pump as shown in figure 8.1. It provides information on several elements of a pump's performance and helps select the most suitable one. The pump curve varies from pump to pump, and the variation depends on factors like electrical power and the size and shape of the impeller.

System Curve

The system curve shows the pressure loss in the system as a function of the flow, and it is known as the system curve. This curve is given by the system in which the pump is to operate. It is a combination of static pressure head and dynamic pressure head. The specific duty point is the cross between the system curve and the pump curve. It is important to stay as close to the duty point as possible, because oversizing and under sizing a pump may have performance consequences.

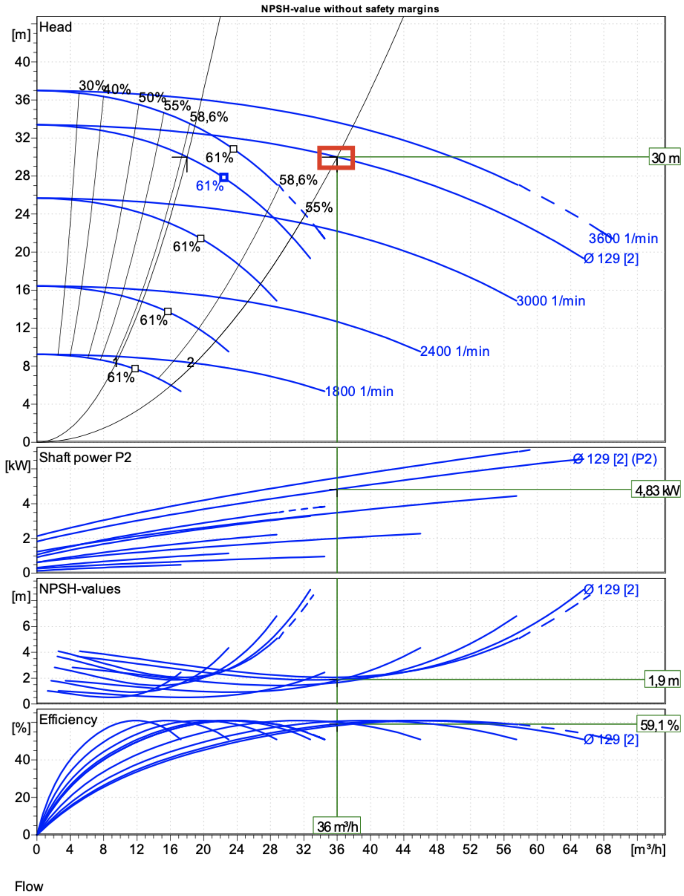


Figure 8.1: Pump curve

QH Curve

The QH curve shows the head that a pump is able to perform at a given flow. The head is measured in meters and one of the advantages is that the QH curve is unaffected by the fluid's density. Low flow results in a high head, and high flow results in a low head. Flow is the rate at which water travels throughout a hydraulic system, while the head denotes the heights at which the pump can elevate a water column.

Shaft Power P2

The shaft power P2 curve illustrates the relationship between the power consumption of the shaft and the flow through the pump. The power consumption determines the size of the electrical installations which must supply the pump with power. Power consumption depends on the density of the fluid. The P2 curve increases as the flow increases.

NPSH Curve

Net Positive Suction Head or NPSH denotes the minimum absolute pressure that must be present on the suction side of a pump to avoid cavitation. Cavitation is when small steam bubbles appear in the pump due to pressure being too low. This can cause damage to the pump. To determine if a pump can operate safely in a system, the NPSH must be known for the largest flow and the evaporation pressure at the given temperature.

The NPSH curve is mainly used when pumping water in a non-closed system. In a closed system such as this, the drop in pressure from elevation will be canceled by the descent of the water column. Since this is not a depressurized system, the NPSH value would never be anywhere near the critical value. This would therefore not be considered.

Shaft Efficiency

Efficiency is the ratio between supplied hydraulic power and power consumed. The efficiency depends on the pump's duty point, underlining the importance of selecting a pump that fits the flow requirement, to ensure that the pump is always working in the most efficient flow range. The supplied power is always larger than the hydraulic power, due to losses in motor and pump components. That is why the efficiency of a complete pump unit is lower than the efficiency of just the pump. The system border for the shaft efficiency is illustrated in figure 8.2. Since the provided efficiency curve is in terms of shaft power, there had to be an assumption about the efficiency of the motor. The efficiency was chosen to be constant at 0.9, this was estimated by comparing results from shaft power and overall power, and it was relatively constant around 0.9. This efficiency is perhaps a little higher than in reality, however, choosing a high efficiency for the motor would be conservative because this would result in a lower potential for energy saving.

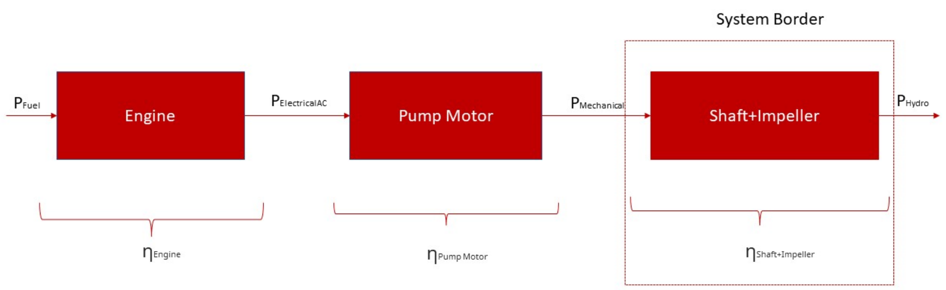


Figure 8.2: Illustration of the system border for the shaft efficiency

8.2 Finding a Suitable Pump

There is a lot to consider when choosing a pump. The system has major variations in flow, ranging from 0.5 m^3/h to 36 m^3/h. The pump must be able to deliver a differential pressure of 3 bar. A few suggestions for a pump were presented after contact with Allweiler, which is one of Vard's pump suppliers. The first suggestion was two pumps connected in parallel with two equal pumps, This would increase the flow range, but it would not affect the differential pressure. For further information about these pumps, see attachment A.16. The Allweiler pump did not comply with the requirements. Grundfos, another pump supplier, was contacted to find a better solution. After receiving the data sheet and suggestion for a pump, it turns out that the efficiency was too low when the flow is 0.5 m^3/h. They therefore suggested a system consisting of four pumps connected in parallel, with one as a backup, see attahcment A.15. With this setup, it is possible to run one or two of the pumps when the demand is low, and run all three during full operation. This ensures an acceptable efficiency at both high and low flows.

8.3 Effect of Frequency Control and Flow Restriction

In order to optimize the system, it is necessary to analyze the effect of frequency control of the pump and restricting the flow in the system. Frequency control is done by changing the frequency of the AC voltage that delivers power to the pump, which changes the speed of the pump motor. The result of the frequency control is to move the pump curve towards or away from the origin, which is illustrated in figure 8.3. By changing the frequency of the pump, it would be possible to move the pump curve such that it would intersect the system curve at the optimal point. This could have the potential for a large power saving in the central heating pump, mainly because of the strange property of Frese dynamic valves. These valves throttle or bypass the system such that the flow in the pipes remains constant as long as the pressure is within the working range of the valves. This would mean that if not accounted for, the valves have to throttle the system to maintain the desired flow, and the pump would have an unnecessary power consumption. Flow restriction can be performed using actuator-controlled pressure-independent valves. These valves throttle the system to ensure that the flow is as desired.

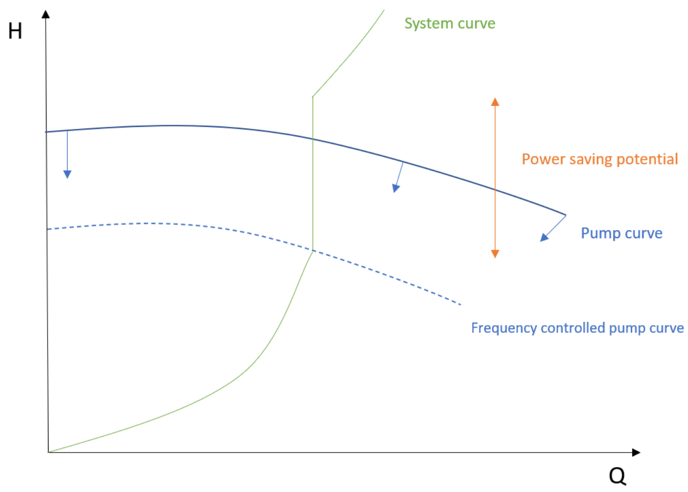


Figure 8.3: The effect of frequency control

To determine what the power-saving potential could be, it would be helpful to estimate the pump curve as a function of the flow and the frequency. This would make it possible to perform calculations with the mathematical function. This was done by using a numerical curve fitting program to estimate a polynomial for the pump curves provided by Allweiler and Grundfos. Firstly, the end points and a middle point at the curve of a constant frequency were considered to estimate a function $H(Q)$. The effects of frequency control also had to be investigated. This was done with an assumption the flow Q and the head H is proportional to a function of the change in frequency C.

$$H(Q, C) = H(Q \cdot f(C)) \cdot g(C) \tag{8.1}$$

The range of the function is also a function of the change in frequency C.

$$Q \in [0, h(C)] \tag{8.2}$$

Where:

$$C = \frac{f_{new}}{f_{Original}} \tag{8.3}$$

With these assumptions, it is possible to estimate these relationships by comparing them to pump curves at different frequencies. That gave the following relationships, which were used to estimate the curve at varying frequencies.

$$H(Q, C) = H(Q\frac{1}{C}) \cdot C^2 \tag{8.4}$$

Where the range of the function is the original range Q_{max} times C.

$$Q \in [0, Q_{max} \cdot C] \tag{8.5}$$

The power consumption of the pump, at a certain point, is given by the following equation.

$$P = \frac{\rho \cdot g \cdot H \cdot Q}{\eta} \tag{8.6}$$

Meaning that the efficiency η has to be considered. This was done similarly to the pump curve, by estimating a polynomial for the efficiency $\eta(Q)$. All the estimated polynomials were second-degree polynomials, the estimation would be more accurate with a higher degree polynomial, however, the estimation would only be as accurate as the accuracy of the graph reading. Therefore, a second-degree polynomial is sufficient. With this information, the polynomials were estimated as shown in table 8.1 and 8.2.

	NB32-125/01 Parallel	**NB32-125/01**	**NB32-160/02**
$H(Q)$	$33.5 + 0.01675Q - 0.00317Q^2$	$33.5 + 0.118Q - 0.0174Q^2$	$34 + 0.2474Q - 0.0115Q^2$
$H(Q,C)$	$(33.5 + 0.01675\frac{Q}{C} - 0.00317\frac{Q}{C}^2)C^2$	$(33.5 + 0.118\frac{Q}{C} - 0.0174\frac{Q}{C}^2)C^2$	$(34 + 0.2474\frac{Q}{C} - 0.0115\frac{Q}{C}^2)C^2$
$\eta(Q)$	$0.0271Q - 0.0003Q^2$	$0.0535Q - 0.0012Q^2$	$0.0481Q - 0.0008Q^2$

Table 8.1: The polynomial used to estimate the pump and efficiency curves at varying flows and frequencies

	Grundfos Hydro Multi-E 4 Single	**Grundfos Hydro Multi-E 4 Parallel**
$H(Q)$	$43.8 + 0.8Q - 0.1321Q^2$	$44.59 + 0.1256Q - 0.0116Q^2$
$H(Q,C)$	$(43.8 + 0.8\frac{Q}{C} - 0.1321\frac{Q}{C}^2)C^2$	$(44.59 + 0.1256\frac{Q}{C} - 0.0116\frac{Q}{C}^2)C^2$
$\eta(Q)$	$0.1361Q - 0.0072Q^2$	$0.0376Q - 0.00054Q^2$

Table 8.2: The polynomial used to estimate the pump and efficiency curves at varying flows and frequencies

With the efficiency curve for the two pump setups in parallel, it is also possible to calculate when it would be beneficial to run several pumps in parallel versus just running one pump. Having several pumps in parallel would be beneficial when the efficiency curve is higher than for just one pump. By solving for the flow, it would be beneficial to run two pumps when the flow is above 29 m^3/h for the NB 32 125/01. For the Grundfos Hydro Multi-E 4 it would be beneficial to run two pumps at flows above 14 m^3/h and three pumps at flow above 27 m^3/h.

8.4 Assumptions About Operating Conditions

To estimate the potential to reduce power consumption, some assumptions about the operating conditions had to be made. Since this is a project about one SOV in general and not for a specific location, a detailed analysis of the weather conditions that the vessel will operate in was considered too time-consuming for this project. The assumptions about operating conditions were therefore based on data from one location where the vessel could operate. The chosen location that was analyzed was Grimsby, England, where the vessel could be used in the Hornsea 2 wind farm. Which is currently the largest offshore wind farm in the world [15].

As a simplification, it was decided to divide the operating conditions into three segments: cold weather, middle weather and warm weather. Weather data from Visual Crossing was analyzed to estimate operating temperatures at Grimsby and at sea. For the cold and warm conditions, the temperatures at the 25 % and 75 % quartiles were used. The humidity was chosen to be constant at an average of 81 %. Although this estimate might not give an accurate picture of the operating conditions, this would give a good enough estimate as long as these assumptions are used in the calculations of the existing system as well as a dynamic system. To estimate the distribution of cold, middle and warm days, it was decided to consider all days with an average temperature below the midpoint between middle and cold as cold days. Likewise, for the warm days, every day above the midpoint between cold and warm days was considered warm days. With these assumptions, the following conditions were considered. The details of the weather analyses can be found in the attachments A.13

Grimsby	Cold conditions	Middle conditions	Warm conditions
Temperature °C	6.4	10	14.4
Distribution throughout year	37%	24%	39%

Table 8.3: Temperatures at Grimsby

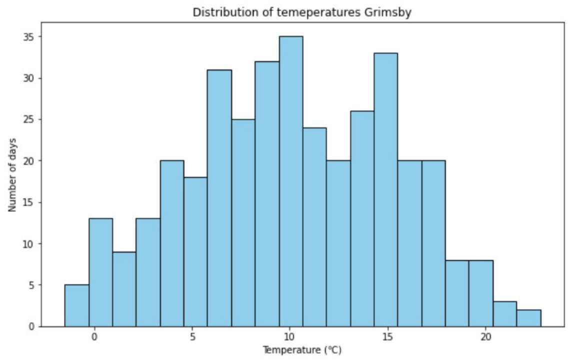


Figure 8.4: Distribution of average daily temperatures at Grimsby [16]

At sea	Cold conditions	Middle conditions	Warm conditions
Temperature °C	7.4	10.5	14
Distribution throughout year	37%	24%	39%

Table 8.4: Temperatures at sea outside of Grimsby

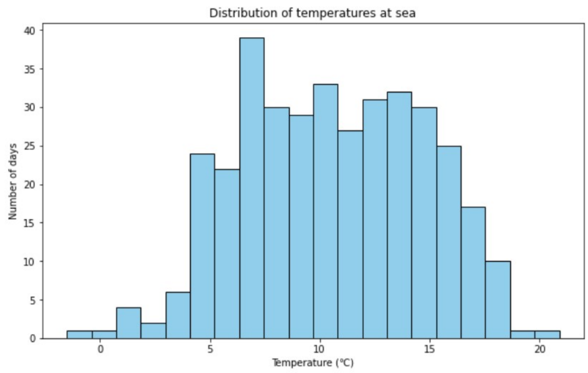


Figure 8.5: Distribution of average daily temperatures at sea outside of Grimsby [17]

8.5 Heat Balance

With the assumptions about the weather conditions, it was possible to calculate the heat balance for each mode and weather condition. This was done by considering the range where the AHUs are active from subsection 7.6 and assuming that there is a linear relationship between the outside temperatures and the consumption of the AHUs in this range. The consumption was then calculated as a percentage of the maximum capacity in each condition. The consumptions for the rest of the consumers were based on conclusions from subsection 7.10.

8.6 Alternatives for a Dynamic Central Heating System

After having explored different solutions to designing a dynamic flow system, it was found that there were two solutions that were promising. This was done by discussing different possibilities with experienced engineers at Vard to determine what realistically could be done to optimize the system.

8.6.1 Frequency Control and Flow Restriction

One of the solutions that were found is to use both frequency control of the central heating pump and to restrict the flow to each consumer to what is desired. This would possibly have the largest power-saving potential of the two solutions. As shown in formula 8.6 this would save power by both lowering the flow delivered by the pump and the pressure drop in the system. At low flows, this configuration would have very little power consumption. The main challenge with this configuration would be to find a way to control the frequency of the pump.

The pump would be at the optimal working point when the differential pressure over all the valves is barely above the minimum working pressure. This will ensure the right flow in all the consumers and that the pump is at the optimal working point. This is illustrated in figure 8.3. This could be done by having sensors over all the dynamic valves that could adjust the frequency of the pump. These sensors would have to be fine-tuned to ensure they are in sync with the independent valves, and the logic of the signal to the actuator, the feedback from the sensors, and the frequency converter would have to be programmed and tested. This could potentially be time-consuming and costly.

This system would also have to account for the possibility of manually closing valves. If there is a leakage somewhere in the pipe system, the differential pressure over the pump would suddenly drop and branches would be closed off manually Until the pressure stabilizes. If one or more of the branches with AHUs are closed off, this would result in no flow through the branch and the differential pressure over the valve would be zero. The pump would then increase the frequency to deliver the right flow to the consumers, which would never happen because the branch is closed. If not accounted for, the frequency would increase until either the surge protector kicks in or the motor burns out. In either case, this is not ideal because this would halt the entire system.

8.6.2 Flow Restriction

The second solution that was found, was to only restrict the flow in the system using actuator-controlled pressure-independent valves. This would also decrease the power consumption for the pump, however, it would not benefit from the decrease in pressure that frequency control would have. The pressure would likely be slightly higher than without flow restriction because of the pump curve. Even if the power saving potential is lower, this configuration has the benefit of being much simpler than with additional frequency control. This would drive development costs down, as well as installation costs and maintenance costs. This system would only differ from the original system by replacing the three-way Oventropp valves and the pressure-independent Frese valve with actuators. This configuration would possibly need a bleed valve to bypass the throttling from the valve, this is to ensure there is always some flow in the system. This is necessary to make sure the pump does not overheat, since the pump is designed to self-cool from the fluid in the system.

Both options would have to be considered when designing the system. The development cost, installation cost and maintenance cost would have to be estimated and compared to the potential for power saving to make a decision on which configuration would be most beneficial for this vessel. Making detailed estimations for these costs would be too comprehensive for this project, however, it is possible to make an educated decision on which configuration to proceed with.

8.7 Calculating the Potential for Energy Saving

In order to compare the two solutions, it is necessary to estimate what the potential for fuel-saving would be in each configuration. This was done using the data gathered above about the three modes that would be considered, the working conditions and information about the AHUs, as shown in figure 8.6. As well as the different pump solutions that were provided by Allweiler and Grundfos. Firstly, it was necessary to develop a mathematical model of the pressure drop in the system. This was done with the assumption that the pressure drop in each pipe section is proportional to the square of the flow. This implies that the pressure drop would obey formula 7.4. Using the calculations of pressure drop, from section 7.7 and the nominal flow used in the calculations, it was possible to assign each section of the main pipeline with a respective k_v value such that the pressure drop could be calculated with varying flows.

By entering the capacity of each consumer in the system, the sheet automatically calculates the flow in each section, and then the pressure drop using the assigned K_v value. That would yield the pressure drop the central heating pump would have to overcome in each configuration and the flow, this is the working point of the pump which can be drawn on the pump curve chart.

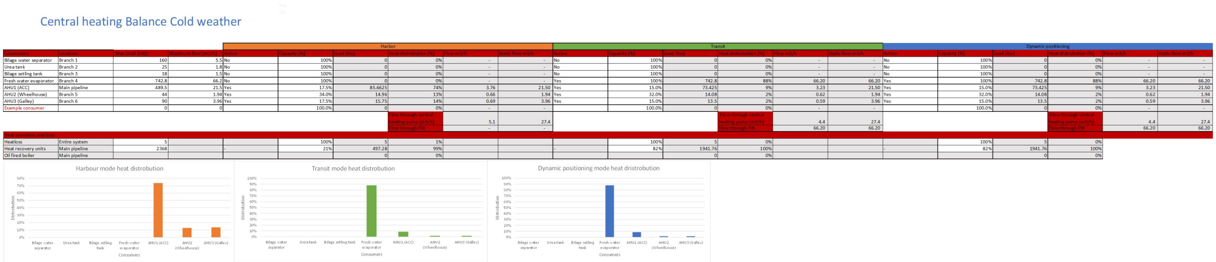


Figure 8.6: Heat calculation during cold conditions

To compare the results with different pump solutions as well as the two different solutions for a dynamic system, this data was used in combination with the polynomials for efficiency and pump curves found in section 8.3. This makes it efficient to compare different solutions in various modes. In the results of these calculations, it was found that the flow is significantly lower than what the system is dimensioned for. Meaning that there is a large potential for power saving from the pump, which leads to fuel savings and lower operating costs.

The difference between the two solutions described in section 8.6 would be that with frequency control it is possible to lower the pressure drop as well as the flow. With just flow restriction it would only be possible to lower the flow, and the pressure drop would be the point on the pump curve at that flow. This is illustrated in figure 8.3. The calculations were done in three versions of the sheet: cold conditions, middle conditions and warm conditions. Where each sheet has three modes: harbor, dynamic positioning and transit. The reason this calculation was done using three different sheets is to keep it simple enough for other users to utilize. There has to be a balance between creating an efficient sheet that could do calculations quickly and still making it general enough, such that it can be used in different projects. It was therefore decided that it would be most user-friendly to do the calculation in three different versions of the document.

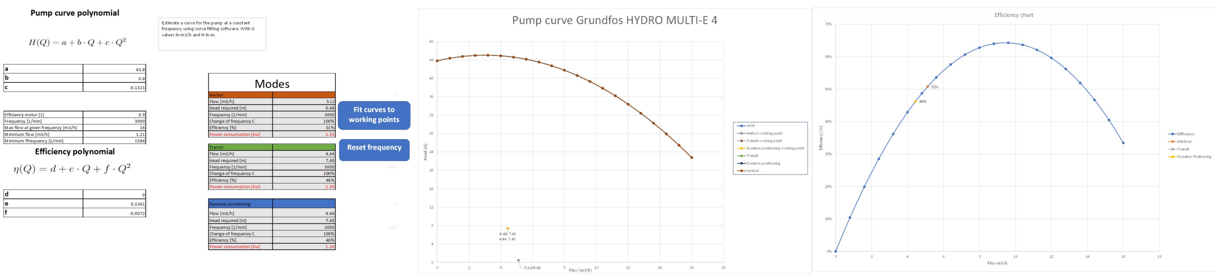


Figure 8.7: Heat calculation during cold conditions.

As shown in figure 8.7 the sheet takes in information about the pump and efficiency curve. The button labeled “Fit curve to working points” runs a macro with the goal seek function in Excel that fits the curve to the working points using frequency control. The button labeled “Reset frequency controlling” re-sets the frequency to the original frequency that is specified. This makes it simple to compare results from the two configurations.

To find the potential for fuel savings, the calculations from the dynamic systems would have to be compared to calculations from the original constant flow system. The calculations from the original system would be done similarly to a dynamic system, the only difference being that the flow would not be restricted by dynamic valves, the flow would be bypassed by the three-way valves, meaning that the flow through the central heating pump would be relatively constant at the value specified in the system documentation. As mentioned in section 7.3 the original pump frequency would be adjusted so that it can deliver flow at the maximum working point. This was found by setting all consumers to full capacity and fitting the pump curve to the working point. It was found that the original pump frequency would be adjusted to around 3513 rpm. This could also be done to a dynamic system using just active flow restriction, however, to include some safety in the calculations this was only done in the calculations for the constant flow system.

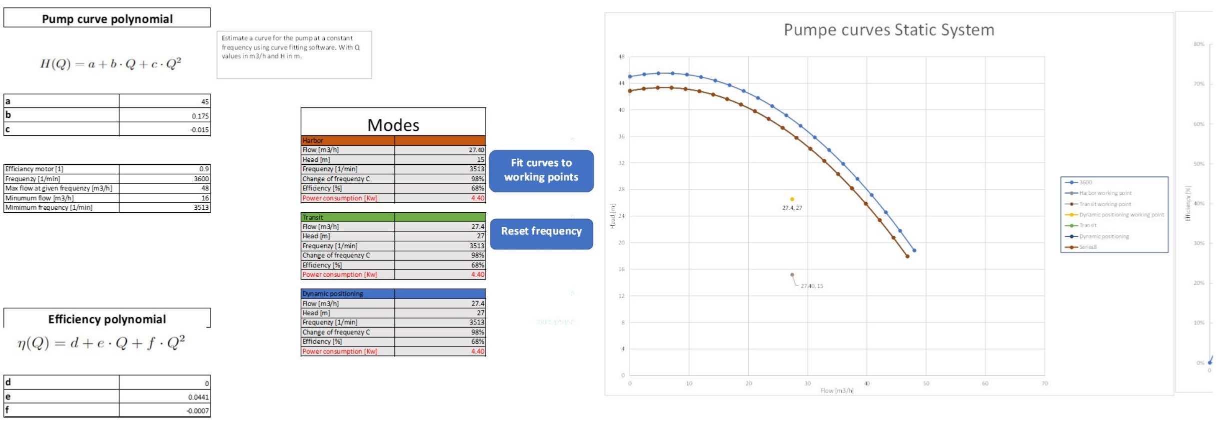


Figure 8.8: Pump calculations in the original constant flow system

Shown below are the calculations from the three weather conditions and three modes. The calculations compare the power consumption of a system that uses flow restriction with a constant pump frequency and a constant flow system that is used today.

8.7.1 Power Consummations Using Flow Restriction

Summary of the pump calculations cold weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	13%
Power consumption [Kw]	3.96
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.93
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.93

NB 32 125/01

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	24%
Power consumption [Kw]	2.15
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	2.11
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	2.11

NB 32-160/02

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	22%
Power consumption [Kw]	2.42
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	20%
Power consumption [Kw]	2.38
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	20%
Power consumption [Kw]	2.38

Grundfos HYDRO MULTI-E 4

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	51%
Power consumption [Kw]	1.35
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	46%
Power consumption [Kw]	1.30
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	46%
Power consumption [Kw]	1.30

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.35
Power saving[Kw]	3.05
Power saving potential [%]	69%
Power consumption scaling factor [1]	0.31
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.30
Power saving[Kw]	3.10
Power saving potential [%]	70%
Power consumption scaling factor [1]	0.30
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.30
Power saving[Kw]	3.10
Power saving potential [%]	70%
Power consumption scaling factor [1]	0.30

Figure 8.9: Summary of power consumption during cold conditions using flow restriction

Summary of the pump calculations middle weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	4.00
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91
0	0
Transit	
Flow [m3/h]	4.00
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91
0	0
Dynamic positioning	
Flow [m3/h]	4.00
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91

NB 32 125/01

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	1.99
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	1.99
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	1.99

NB 32-160/02

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	2.26
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	9%
Power consumption [Kw]	2.25
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	9%
Power consumption [Kw]	2.25

Grundfos HYDRO MULTI-E 4

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	25%
Power consumption [Kw]	1.12
0	0
Transit	
Flow [m3/h]	1.66
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	1.09
0	0
Dynamic positioning	
Flow [m3/h]	1.66
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	1.09

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.12
Power saving[Kw]	3.28
Power saving potential [%]	75%
Power consumption scaling factor [1]	0.25
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.09
Power saving[Kw]	3.31
Power saving potential [%]	75%
Power consumption scaling factor [1]	0.25
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.09
Power saving[Kw]	3.31
Power saving potential [%]	75%
Power consumption scaling factor [1]	0.25

Figure 8.10: Summary of power consumption during average weather conditions using flow restriction

Summary of the pump calculations warm weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	4.00
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91
0	0
Transit	
Flow [m3/h]	4.00
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91
0	0
Dynamic positioning	
Flow [m3/h]	4.00
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	3.91

NB 32 125/01

Harbor	
Flow [m3/h]	2.00
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	1.99
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	1.99
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	1.99

NB 32-160/02

Harbor	
Flow [m3/h]	2.00
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	9%
Power consumption [Kw]	2.25
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	9%
Power consumption [Kw]	2.25
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	9%
Power consumption [Kw]	2.25

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Harbor	
Flow [m3/h]	1.21
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	15%
Power consumption [Kw]	1.06
0	0
Transit	
Flow [m3/h]	1.21
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	15%
Power consumption [Kw]	1.06
0	0
Dynamic positioning	
Flow [m3/h]	1.21
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	15%
Power consumption [Kw]	1.06

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.06
Power saving[Kw]	3.34
Power saving potential [%]	76%
Power consumption scaling factor [1]	0.24
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.06
Power saving[Kw]	3.34
Power saving potential [%]	76%
Power consumption scaling factor [1]	0.24
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.06
Power saving[Kw]	3.34
Power saving potential [%]	76%
Power consumption scaling factor [1]	0.24

Figure 8.11: Summary of power consumption during warm conditions using flow restriction

8.7.2 Power Consumption Using Flow Restriction and Frequency Control

Summary of the pump calculations cold weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	13%
Power consumption [Kw]	1.09
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	11%
Power consumption [Kw]	1.09
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	11%
Power consumption [Kw]	1.09

NB 32 125/01

Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	24%
Power consumption [Kw]	0.58
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	21%
Power consumption [Kw]	0.58
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	21%
Power consumption [Kw]	0.58

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Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	22%
Power consumption [Kw]	1.13
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	20%
Power consumption [Kw]	1.12
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	20%
Power consumption [Kw]	1.12

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Harbor	
Flow [m3/h]	5.12
Head required [m]	0
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	51%
Power consumption [Kw]	0.33
0	0
Transit	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	46%
Power consumption [Kw]	0.33
0	0
Dynamic positioning	
Flow [m3/h]	4.44
Head required [m]	7
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	46%
Power consumption [Kw]	0.33

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.33
Power saving[Kw]	4.07
Power saving potential [%]	92%
Power consumption scaling factor [1]	0.08
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.33
Power saving[Kw]	4.06
Power saving potential [%]	92%
Power consumption scaling factor [1]	0.08
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.33
Power saving[Kw]	4.06
Power saving potential [%]	92%
Power consumption scaling factor [1]	0.08

Figure 8.12: Summary of power consumption during cold conditions using both flow restriction and frequency control

Summary of the pump calculations middle weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	4.00
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08
0	0
Transit	
Flow [m3/h]	4.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08
0	0
Dynamic positioning	
Flow [m3/h]	4.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08

NB 32 125/01

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	11%
Power consumption [Kw]	0.55
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	0.55
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	0.55

NB 32-160/02

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	10%
Power consumption [Kw]	1.05
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	9%
Power consumption [Kw]	1.05
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	7
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	9%
Power consumption [Kw]	1.05

Grundfos HYDRO MULTI-E 4

Harbor	
Flow [m3/h]	2.06
Head required [m]	0
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	25%
Power consumption [Kw]	0.31
0	0
Transit	
Flow [m3/h]	1.66
Head required [m]	7
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	21%
Power consumption [Kw]	0.31
0	0
Dynamic positioning	
Flow [m3/h]	1.66
Head required [m]	7
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	21%
Power consumption [Kw]	0.31

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.31
Power saving[Kw]	4.09
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.31
Power saving[Kw]	4.09
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.31
Power saving[Kw]	4.09
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07

Figure 8.13: Summary of power consumption during average weather conditions using both flow restriction and frequency control

Summary of the pump calculations warm weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	4.00
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08
0	0
Transit	
Flow [m3/h]	4.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08
0	0
Dynamic positioning	
Flow [m3/h]	4.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	1.08

NB 32 125/01

Harbor	
Flow [m3/h]	2.00
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	0.55
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	0.55
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	53%
Efficiency [%]	10%
Power consumption [Kw]	0.55

NB 32-160/02

Harbor	
Flow [m3/h]	2.00
Head required [m]	0
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	9%
Power consumption [Kw]	1.05
0	0
Transit	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	9%
Power consumption [Kw]	1.05
0	0
Dynamic positioning	
Flow [m3/h]	2.00
Head required [m]	6
Frequenzy [1/min]	1800
Change of frequenzy C	68%
Efficiency [%]	9%
Power consumption [Kw]	1.05

Grundfos HYDRO MULTI-E 4

Harbor	
Flow [m3/h]	1.21
Head required [m]	0
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	15%
Power consumption [Kw]	0.30
0	0
Transit	
Flow [m3/h]	1.21
Head required [m]	6
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	15%
Power consumption [Kw]	0.30
0	0
Dynamic positioning	
Flow [m3/h]	1.21
Head required [m]	6
Frequenzy [1/min]	1584
Change of frequenzy C	53%
Efficiency [%]	15%
Power consumption [Kw]	0.30

Static system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.30
Power saving[Kw]	4.10
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.30
Power saving[Kw]	4.10
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	0.30
Power saving[Kw]	4.10
Power saving potential [%]	93%
Power consumption scaling factor [1]	0.07

Figure 8.14: Summary of power consumption during warm conditions using both flow restriction and frequency control

As shown in the tables above, there is a large potential for power saving in the central heating pump. As expected, the largest potential is with both flow restriction and frequency control, although the difference in power savings between the two solutions was surprisingly small. The two solutions have the potential to save $\sim$ 70-80 % and $\sim$ 90 % of the power consumed by the central heating pump respectively, where the largest potential is during warm conditions. This is because with a constant flow system, the power consumption is relatively constant, even if the demand for heat is low. This implies that if a vessel operates in warmer conditions than were assumed, then the potential for power saving would be even greater.

The pumps that were compared had some limitations in flow and frequency range that had to be accounted for. Because of the large variations of flow and pressure drop, it was hard to find a pump configuration that would be able to work well at low capacity, while still being cost-efficient. This is therefore a necessary compromise to keep the costs low, however as the calculations show there is still a large potential to save power.

8.7.3 Electrical Load Calculations

This vessel has four engines, with a marine diesel generator. Two of the engines are Caterpillar 3512C as shown in figure 8.15, with electric output of 1700 ekW. The other two engines are the Caterpillar C32 as shown in figure 8.16, with an electric output of 940 ekW. In harbour mode there is only one engine in use with 940 ekW in and the power load is 81 %. DP mode uses all four engines, each of which has a power load of 73.1 %. Also, transit mode has all engines in use, with each engine having a power load of 77.6 %.

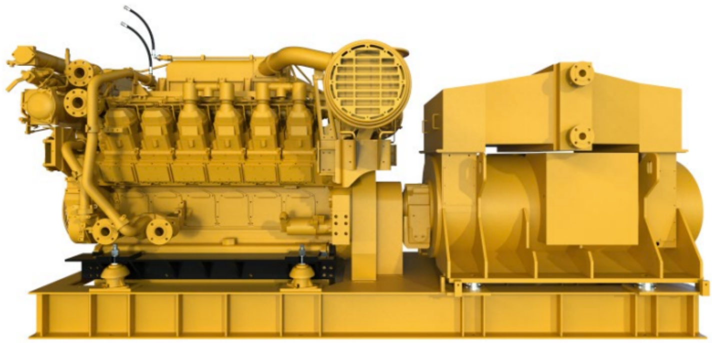

Figure 8.15: Caterpillar 3512C engine

[18]

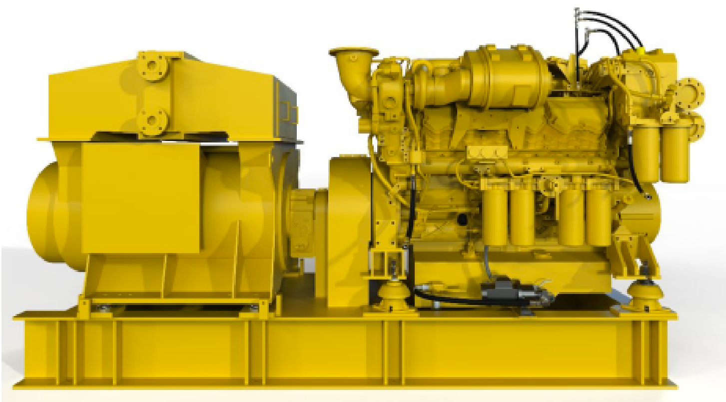

Figure 8.16: Caterpillar C32 engine

[19]

The fuel consumption per ekWh produced by the engines is also specified is specified in the datasheet. These values can be found in figure 8.17.

Fuel Consumption data	
Harbor	
Fuel consumption per [g/Kwh]	215.50
Transit	
Fuel consumption per [g/Kwh]	202.80
Dynamic positioning	
Fuel consumption per [g/Kwh]	203.25

Figure 8.17: Fuel consumption per ekWh generated by the engines

8.7.4 Potential Fuel Savings

To calculate the potential savings would be the fuel price has to be considered as well. The engines use Marine Gas Oil (DMA/MGO) fuel, to find an estimation of the average fuel price, a contact person from Bunker Oil Norway was contacted. The average price was found to be 18 kr/L. In this project, it is assumed that the vessel will operate with Norwegian fuel prices.

8.7.5 Potential Emissions Savings

The potential fuel savings would also result in a reduced environmental impact on the vessel. The environmental impact can be quantized by calculating the potential reduction of greenhouse gasses, caused by fuel consumption.

CO2

CO_2 is a well-known greenhouse gas. It is abundant in the atmosphere, however high concentrations of it cause a greenhouse effect. It is common to compare other greenhouse gasses with an CO_2 equivalent, this is because CO_2 is the most well-known greenhouse gas, which makes this a good metric to compare different types of emissions [20].

NOx

NOx is a common term for nitrogen oxides: N_2O, NO, N_2O_3, NO_2. These are all poisonous gasses and can cause asthma and other respirational infections [21].

CO

CO is an odorless and colorless gas that is a common component in air pollution. High concentrations of the gas can cause major health problems by restricting oxygen delivery to the cells. Lower concentrations of it can also increase the risk of cardiovascular disease [22].

HC

HC gas is a common term for different hydrocarbons, including methane and propane. Which are gasses composed of only hydrogen and carbon bonds. These gasses are known to cause major health risks such as the increased risk of cancer and they can have a large environmental impact depending on which type of HC gas that is present [23].

Part Matter

Part matter is a common term for particles such as soot, ash, or fluid that are emitted as a result of incomplete combustion. This is most common in diesel combustion. Exposure to part matters can increase the risk of skin cancer, lung cancer and bladder cancer. It can also cause damage to the genetic material [24].

The emissions were calculated by using the provided specification for emissions per hour of engine runtime and fuel consumption per hour at a specific engine speed. The calculation was done with the specifications for the CAT 3512C engine. Even if the fuel consumption and emissions values differ, the relation between the two is relatively unchanged. The emissions were specified as grams per hour, for these purposes it would be beneficial to convert this to grams of emissions per kg of fuel consumed. If it's assumed that the emissions per hour and fuel consumption per hour are constant, then the relation between them would be as shown in formula 8.7.

$$\frac{Emissions/hr}{V_{fuel}/hr} = \frac{Emissions}{V_{fuel}} \tag{8.7}$$

To convert this to unit mass, the density of the fuel would have to be considered. For DMO/GMA the density is 0.89 kg/L and the mass can be found by the relation between mass and volume.

$$\begin{aligned} &\rho_{fuel} = \frac{V_{fuel}}{m_{fuel}} \\ &V_{fuel} = m_{fuel} \cdot \rho_{fuel} \\ &\frac{Emissions}{m_{Fuel}} = \frac{Emissions/hr}{V_{fuel}/hr \cdot \rho_{fuel}} \end{aligned} \tag{8.8}$$

That yields the following data for grams of emissions per kg of fuel.

	Hourly emissions	Hourly fuel consumption	Emissions per unit mass of fuel consumed
Units	kg/hr	L/hr	g/kg fuel
CO_2	841	323.9	2918
NOx	8547	323.9	29649
CO	458	323.9	1189
HC	265	323.9	919
Part matter	69.6	323.9	241

Table 8.5: Emission data per unit mass of fuel consumed [19]

9 Concept for a Dynamic System

By considering the results from the power consumption calculations and the available options for controlling. The solution that was chosen was a dynamic flow system using just flow restriction by throttling, without automatic frequency control. Even if a system using active frequency control to reduce the pressure drop, would be even more efficient. The reason this was chosen was to reduce the installation and development costs. As the power consumption calculations show, this system would still have a large impact on power consumption. This new system would require different pumps and dynamic valves. The three-way motor-operated valve and the dynamic valves which are placed on each AHU are replaced with dynamic valves.

9.1 Choice of Pump System

The selected pump is a Grundfos Hydro Multi-E 4 CRE 10-3 as shown in figure 9.1. This is the pump that proved to be the most efficient by the calculations in section 8.6. This pump has a different pipe dimension on the inlet/outlet than the original pump, which means the pipe dimensions would have to be changed to DN80 instead of DN100. The selected pump system has four pumps connected in parallel, with one of the pumps used as a backup.

Figure 9.1: Grundfos Hydro Multi-E 4 CRE 10-3

[25]

9.2 Choice of Valves

9.2.1 Pressure Independent Actuator Controlled Valves

In order to control the flow to the AHUs there has to be installed pressure independent dynamic valves. These valves ensure that the flow in each branch is as desired, as long as the pressure is between the working range. The selected dynamic valves are Frese Optima Compact with actuator control, illustrated in figure 9.2, these valves can be programmed to deliver a set flow based on the temperature of the air current going out from the AHUs. These valves would replace the three-way valves and the pressure-independent valves, currently located by the three AHUs. These valves have the possibility to fully close the flow, however, they have a minimum required flow that guarantees the right flow. If the valves are controlled by temperature output, this would not be a problem, since the valve would regulate to deliver the desired temperature output.

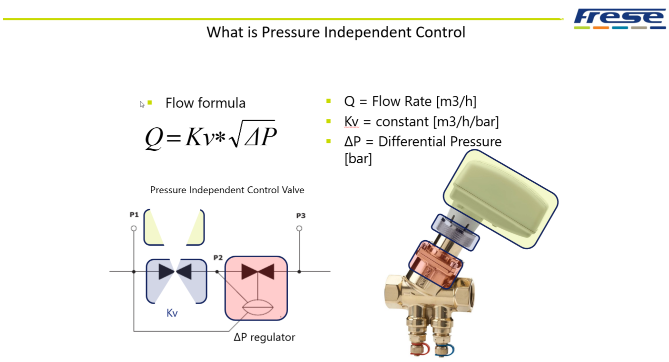

Figure 9.2: Frese Actuator Control Valve

[11]

9.2.2 Bleed Valve

To ensure the flow through the central heating pump is always above the minimum requirement, there has to be installed a bleed valve. This is a valve that bypasses the consumers with a constant minimum flow, unlike the three-way valves that bypass the consumer to control the heat, and the flow through the bleed valves is much smaller. The placement of these valves can be found in the attachment A.2. These valves are installed by the consumer that has the lowest differential pressure over it, this is to ensure that none of the consumers will be bypassed by the bleed valve. In this case, the bleed valve will be installed by AHU1.

The valve that was chosen was a Frese Sigma Compact DN25 High valve. This valve has a flow range from 0.14-2.4 m^3/h, which means that it will be suitable to ensure a minimum flow through the pump at 1.21 m^3/h. This valve will have a constant flow, that would have to be accounted for. This was considered when concluding the power consumption savings, although this has very little effect.

9.3 Performance during Worst-Case Scenario

Even if this central heating system likely would never operate at full capacity over longer periods of time, except during the startup of the system, it is still important that the system can function even in a worst-case scenario. The worst-case scenario for this system would be where all the consumers are in use at 100 % capacity. To determine if the system would function properly, the power consumption spreadsheet was once again used to calculate the power consumption. Similar to the calculations done in cold, middle and warm conditions, however in this calculation all the consumers were set to active, and at a 100 % capacity. The results of the calculations are shown in figure 9.3 and 9.4.

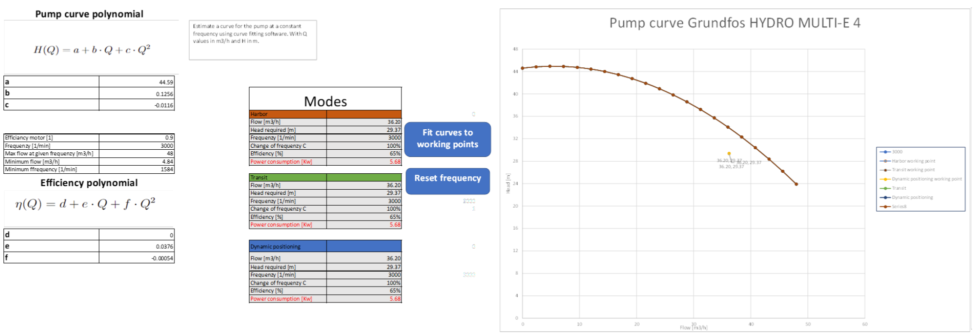

Figure 9.3: Pump calculations during worst case scenario for the Hydro Multi-E 4 pump

Pump power consumption saving	
Harbor	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20
Transit	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20
Dynamic positioning	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20

Figure 9.4: Pump calculations summary comparing the original system with a dynamic system

These calculations show that the chosen pump system would function even at full capacity, with an efficiency of ~ 65 % which could be considered acceptable. The efficiency of the pump at this working point is somewhat lower than the original pump. This is because the original pump is optimized to work at this working point. Since the system likely would never work at this point over longer periods of time, this is acceptable. It can therefore be concluded that this system would also work well at full capacity.

9.4 Conclusions of the Total Savings

Now that all the components for the dynamic central heating system have been assessed and considering the assumptions made in section 8 it is possible to come to a conclusion of the total annual savings in fuel costs and emissions.

Summary of potential annual savings from all weather conditions	Cold conditions	Middle conditions	Warm conditions	Total annual savings
Total annual savings	NOK 35 799	NOK 24 952	NOK 41 868	NOK 102 619
Total annual fuel saving [kg]	1989	1386	2326	5 701
		Emissions		
Annual Co2 emissions [kg]	5803	4045	6787	16636
Annual Nox emissions [kg]	59.0	41.1	69.0	169.0
Annual Co emissions [kg]	3.2	2.2	3.7	9.1
Annual HC emissions [kg]	1.8	1.3	2.1	5.2
Annual part matter emissions [kg]	0.5	0.3	0.6	1.4
		Power scaling factor		
Harbor	0.33	0.27	0.24	0.28
Potential power saving [%]	0.67	0.73	0.76	72%
Distrobution throughout year	5.6%	3.6%	5.9%	15.0%
	0	0	0	
Transit	0.32	0.27	0.25	0.28
Potential power saving [%]	68%	73%	75%	72%
Distrobution throughout year	1%	1%	1%	3.5%
	0	0	0	
Dynamic positioning	0.32	0.27	0.25	0.28
Potential power saving [%]	68%	73%	75%	72%
Distrobution throughout year [%]	30%	20%	32%	82%
	0	0	0	
			Total Power saving factor	0.28
	Yearly distrobution check:	100%	Total power saving [%]	72%

Figure 9.5: Conclusions for the total annual savings in a dynamic central heating system using flow restriction

As shown in figure 9.5 the annual fuel-saving potential is 5 800 Kg/year, which would result in a reduction of fuel cost of 100 000 NOK/year. The details of greenhouse gas savings can be found under the "Total annual savings" column in the rows marked in green.

By considering the distribution spent in each mode and weather condition, it was also possible to calculate an average power saving factor, which is the proportional power saving in the central heating pump. This was calculated to be 0.28 on average, meaning that the power consumption in this optimized system is 28 % of the original system. This is an average power-saving potential of 72 %. It is important that this potential for power saving is for the central heating pump, this should not be confused with the total fuel consumption for the vessel, the power saving in the pump would be minuscule compared to the power consumption of the entire vessel.

9.5 System Documents

The documents described in this section are important system documents, normally produced by the machinery department when designing a system such as this. These documents help communicate the purpose and logic of the system to other departments, as well as other parties with an interest in the project.

P & ID

The Piping & Instrumentation Diagram (P & ID) shows the system schematically with pipe dimensions and valves. This is a schematic drawing of the components in the system, as well as the piping.
A.2

System Description

This is the written description to use alongside the P & ID and explains the system briefly. This makes it easy for someone to understand how the system works and how the components cooperate. This is very similar to the abstract of function, however, this document is less technical. The system description is meant to be understood by a person having some technical understanding, unlike the abstract of function, which requires slightly more knowledge about the system in general.
A.3

Abstract of Function

The abstract of function is a document that describes the contents in the P & ID in plain text. As the name implies, this is an abstract of how the system functions, where all the main components are described.
A.4

Armature List

This list shows all the components, including supplier and size. The armature list contains more detailed information of each component in the P & ID.
A.5

9.6 Eco Design

Eco design are requirements set by the EU and applies to electric motors that use variable-speed drives. This implies that these regulations apply to the central heating pump used in this project. The regulations set requirements for the efficiency of the pumps.

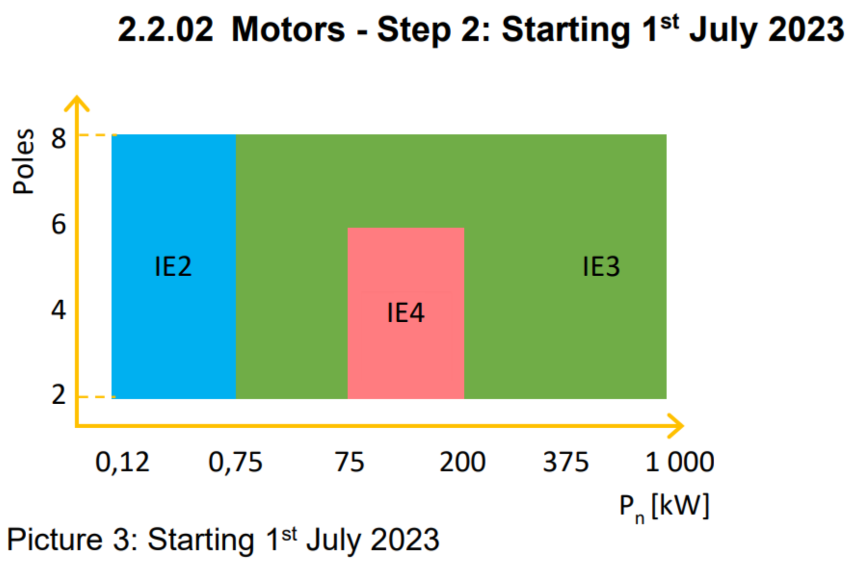

Figure 9.6: Eco design regulations for motors starting July 1st 2023

Since the pumps have a power rating above 0.75 kW and below 75 kW, and the motor has two poles, the regulations require the pumps to be in an efficiency class of IE3 or above [26]. In the Grundfos data sheet it is specified that the pumps have an efficiency rating of IE5, which means that these pumps satisfy EU regulations for eco design.

9.7 How Can This Work be Used in Future Projects

The calculations done in this project are done on a relatively small central heating system. Meaning that there is potential for even greater savings in larger systems. It is therefore important that the work done with this system can be transferred to other projects. The results from these calculations could be used directly as a factor to estimate the power savings as a proportion to the current power consumption, or the documents produced in this project can be used to do a more detailed calculation. The documents were therefore created such that it would be easy for other engineers to do calculations for similar projects.

Calculations on a similar project will probably be done by engineers at Vard Design &

Engineering, it can therefore be assumed that the final users of these documents will have some understanding of software such as SF Pressure Drop and Microsoft Excel. This is something that will be accounted for when considering the user-friendliness of these documents.

A good indication of the proportional savings in other central heating systems is the relation between the capacity that the system is normally running, versus the capacity that the system is designed to run at. The existing system on this vessel, for example, is designed to deliver flows at 36.2 m^3/h, however, it usually requires flows significantly lower than that. This means that the system has great potential. A system that is normally running at a capacity close to full capacity, would probably have a much smaller potential.

9.7.1 User Tests

It is important that the work done in this project can be utilized in future projects. Therefore, the method to perform these calculations has to be user-friendly. To make it easy for other users to use this method for calculating potential fuel savings, a user manual was created for the entire procedure. This can be found in attachment A.1. To make sure the user manual and documents were as user-friendly as possible, engineers at Vard were provided the user manual and documents without further explanation of how to use the method to do calculations. The feedback received was positive that this is something that can be used in future projects.

10 Economic Analysis

When considering if switching to a dynamic system would be financially beneficial, an economic analysis has to be performed. This analysis accounts for the increased purchase costs as well as the annual potential for fuel savings. When it comes to the installation and maintenance cost, there is no indication that this system would have higher costs, since it is very similar to the existing system with just some modifications in a few of the parts. There is a possibility that these costs would be lower in a dynamic flow system, since a pump running at lower capacity would have less wear and there are fewer parts that have to be installed. Nevertheless, this analysis will not consider a difference in installation and maintenance costs.

10.1 Purchase Cost

The increased purchase cost can be assessed by considering the cost of the original parts, compared to the cost of the parts needed for the dynamic central heating system. The parts that will no longer be used are Oventropp three-way valve, Frese Sigma Compact valve for AHU1, AHU2 and AHU3 and Grundfos CR32-2-2 pump.

The parts that have to be installed in the new system are Frese Optima Compact for AHU1, 2, and 3, Frese Sigma Compact as a bleed valve, and Grundfos HYDRO MULTI-E 4 CRIE 10-3 circulation pump.

Because of competitive advantages, the exact prices of specific parts cannot be revealed, although the difference in price between the two systems will be used for economic analysis. The price difference was calculated by contacting the suppliers and asking for a price estimation for each part. The euro exchange rate that was used was the exchange rate as of May 9$^{\text{th}}$ 2023, even if the exchange rate would vary, this is just an indication of the economic benefit. The new pump is quite a bit more expensive than the original pump, while the price of the armature is relatively unchanged. A summary of the price difference can be found in table 10.1, where a positive value indicates the increased cost of a dynamic system.

Price difference on armature	-18 598 kr
Price difference on pump system	230 771 kr
Total price difference	212 173 kr

Table 10.1: Price difference for armature and pump system

10.2 Return on Investment

With the conclusions from sections 9.4 and 10.1 it is now possible to determine a return on investment. This is an indication of the amount of time before the economic benefits would outperform the increased costs. This would provide a value that makes it easy for a customer to visualize the benefits, and therefore easier to sell.

Total increase of purchase costs	212 173 kr
Annual savings	102 619 kr/year
Return on investment	2.1 years

Table 10.2: Total increase of purchase costs, annual savings and return on investment

11 Possibilities for the Use of Alternative Fuels

Because of the limited timeframe, it was decided to not include part four of the project in this project. This was done in cooperation with our supervisor at Vard Design & Engineering, Runar Fiske and our supervisor at NTNU, Lars Petter Bryne. While this segment was intended to be optional rather than mandatory, its inclusion hinged on the availability of sufficient time. As of writing this May 10^{th} 2023 it is evident that this part has to be abandoned. If this part were to be included, it would not be comprehensive enough to actually bring something useful to this project. It was instead decided to focus on the three other parts of the project.

12 Conclusion

The purpose of this project was to investigate if there is potential to save power by doing changes to an already existing central heating system onboard a service operative vessel. Previously to this project, it was suspected that changing from a system using constant flow, to a system that dynamically controls the flow and differential pressure could save a significant amount of power, which results in lower fuel consumption and greenhouse gas emissions. This was something Vard Design & Engineering wanted to confirm.

In this project, the group analyzed an existing central heating system and performed calculations such as pressure drop, heat loss, and heat demand. With these results, it was possible to come up with alternative solutions for the central heating system, to lower the power consumption. In this project, the main emphasis has been on optimization of the pumps. There were two solutions that were considered for a dynamic flow system. The first solution was a system that uses both frequency control of the pumps, along with flow restriction to each consumer. The second solution was a system using just flow restriction. Expectedly, it was found that the first solution had the greatest potential for power saving, however, this system would be significantly more complex than the second solution. It was therefore decided to proceed with a system using just flow restriction. The system has been redesigned with changes in some valves, as well as the pump system. It was concluded this system has the potential to save $\sim$70 % of the power consumed by the central heating pumps, which results in an annual fuel saving of $\sim$100 000 NOK. With the estimated increase in installation costs compared to the original constant flow system, this investment would have a return on investment of 2.1 years.

After finishing this project, the group is convinced that the topics presented in this project should be explored further. The calculations made here show that there could be a large potential to save fuel in a relatively small central heating system, however, it can therefore be concluded that this research is worth proceeding with.

13 Future Work

While this project contains a comprehensive comparison of a system using constant flow and a system using various solutions for dynamic flow, there are still some improvements that can be done to the system. Unfortunately, there was not enough time to include these topics in the project, however, this section presents some suggestions on topics that could further improve this system.

13.1 Belimo Energy Valves

Pressure-independent flow and power control and transparent monitoring of heating systems are provided by the Belimo Energy valve. These valves are ensuring that they are not operated with a low temperature difference in the central heating fluid. According to the supplier, these valves are intelligent pressure-independent valves that can be connected to Belimo Cloud. Which is an application that monitors energy consumption and provides evaluations to improve product and system quality.

13.2 User Interface

In order to do calculations on similar vessels efficiently, it is important that the method and documents used to do the calculations are as user-friendly as possible. The feedback received from what has been produced in this project was positive, however, there is still room for improvement. Even if this method would possibly save a lot of time from doing the calculations from scratch, it is still a time-consuming process. Creating software to fully automate the process of calculating fuel save potential would be too comprehensive for this system. Still, this is something that can be explored in future systems. There is a possibility to use the 3D-model along with simulation software to automatize the pressure-drop calculations and use the results in the power consumption calculations.

13.3 Verifying the Calculations

Manual calculations have an uncertainty that must be taken into account. The results from these calculations should therefore be compared to real-life experiments. Values such as pressure drop, heat loss, and power consumption of the pump should be compared to empirical data.

13.4 Further Improvements of the Pumping System

As of now the central heating pump and the freshwater evaporator pump are connected in parallel. There is a possibility that it could be beneficial to gather these two pumps in one pump system and control the entire system using pressure-independent valves, and frequency control. This would increase the range the pumps have to work well in, and it should be investigated if this has the potential to save even more power.
The possibility to connect the fresh water evaporator branch to the main pumping system could be explored. This would require an upscaling of the main pumping system. A possibility could be to connect several pumps in parallel with the two existing pumps and have them work together, with one as a backup. This would have to be explored further.

13.5 Alternative Fuels

The possibility to utilize an alternative fuel for this central heating system is also something that should be explored further. This can be done by using fuel like methanol, hydrogen, ammonia, or other low-carbon fuels. These fuels can be used to provide heat and replacing the oil heating that is occasionally used when the heat from the engines are low. There is also a possibility to use alternative fuels to generate electricity for the central heating system, as well as the rest of the vessel. The implications that these fuels would have is something that should be explored further.

13.6 Exploring how the Calculations Scale

As mentioned earlier, these calculations were done on a relatively small central heating system, it is still unclear however how these results would scale in a different size system. The proportional savings are probably dependent on the relationship between what the system is designed to work at, and what the system is normally working at. If the proportional savings is linear to the size of the pump, then transferring these results to systems of different sizes would be very easy, with the power saving factor explained in subsection 9.4. This is something that would have to be explored further in order to be verified.

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A Attachments

A.1 Pump Calculation User Manual

Calculating the Potential Fuel Savings in a Central Heating System

Introduction

This is a user manual on how to calculate the potential for fuel savings as well as savings in emissions for a central heating system. This can be achieved by switching from a constant flow system to a system using dynamic valves to regulate the flow in the system.

A constant flow system is hereby used to describe a system using a fixed pump speed with three-way regulating valves to bypass the flow to obtain the desired temperature output. In most cases, this is wasteful since the pump uses unnecessary power to pump the excess fluid around the system.

The power consumption of the pump can be reduced by having flow-regulating valves as well as a frequency-controlled pump, resulting in lower fuel consumption. This method compares results from just flow-regulating valves with a constant pump speed, a system using both flow-regulating valves and frequency controlling and a traditional constant flow system.

The results from this calculation will have significant uncertainty, however it will give an indication of what the potential fuel savings could be.

Step 1 – split and measure the pipe system

Gain an overview of the system and the consumers. Then chose the main pipeline where the flow is assumed to be highest. Split it into sections and branches where the pipe changes dimensions or where it's natural to split it.
Measure the entire piping system, all the bends and everything that will result in a pressure drop. The 3D-model in Navisworks is very helpful. If some pipes don't exist in the model, measure it in GA in AutoCAD.
All the measurements can be typed into the template Pipe Dimensions as shown in the screenshot below.

		Branch 1 Hot side	Branch 2 Cold side	Bilge water seperator
	Unit	Value		Value
Pipe diameter	mm	DN50	DN50	DN50
Inner diameter	mm	51.3	51.3	51.3
External diameter	mm	60.3	60.3	60.3
Bending radius	mm	90.45	90.45	90.45
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	5.5	5.5	5.5
Length of pipes	m	13.3	4.22	
Bends	deg	3x40deg, 7x90deg, 1x30deg, 2x45deg, 2x50deg, 1x35deg		
Other losses (enlargements, contractions etc)	deg	2xbutterfly valve Kv=115.7, 1xdynamic valve contraction (50-25mm, 9deg) enlargement (25-50mm, 9deg)		0.21bar pressure drop

This template also calculates the heat loss in the pipe system. Based on the outer diameter, length of pipes and k-value the formula $A_O * k$ can be used to calculate heat loss per degree. The total heat loss in the system is presented in the sheet called *Heat loss Summary.*

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	0.030
Outer radius r2	m	0.06015	0.06015	0.06015
Outer radius of pipe r1	m	0.03015	0.03015	0.03015
Innter radius r0	m	0.02565	0.02565	0.02565
Heat transfer rate k	w/m2k	0.971	0.971	0.971
Ao*k [w/k]	W/k	4.883	1.549	0.000
Cold side summary	w/k	0.000	1.549	0.000
Hot side summary	w/k	4.883	0.000	0.000

Step 2 – Calculate the Pressure-Drop at Full Flow

Once all the components causing a pressure drop have been located the pressure drop at full flow in the entire system can be calculated. This can be done with numerical pressure drop software such as SF Pressure Drop, with the attached template. Calculate the pressure drop in the main pipeline in one sheet, then all the branches in their own sheet. The results from the pressure drop can then be compared in the calculation summary. Specify which "column" each branch exits and enters the main pipeline. The "column" refers to the number in row two of the main pipeline sheet.

Column Comparison	
Branch 1	
Inlet Column	6
Outlet Column	40
Pressure through main pipe (bar)	1.35
Pressure through branching pipe (bar)	0.13
Pressure through the main pipe has the most severe pressure drop	

Figure 1 Branch 1 exits the main pipeline at column 6 and reenters at column 40. This means that the pressure-drop through the main pipeline is more severe.

The results from this calculation will be compared and this will determine which path has the most severe pressure drop. Sum up the pressure drop in row 39 for each section in the main pipeline that has the same flow and use this value to assign a kv value for each section. This vale will be used further in the method to calculate pressure drop at varying flows.

Project:		Section 0			Section 1		
Column nr.		1	2	3	4	5	6
1. Flow medium							
Flow medium		Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	36.2	36.2	36.2	36.2	36.2	36.2
Mass flow	kg/h	36134.84	36134.84	36134.84	36134.84	36134.84	36134.84
Volume flow branch.pipe	m3/h						
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
5. Kv value							
Kv value for this node		0.003			0.01		
Kv value of section		639.52			342.39		

Figure 2 Section 0 has a cumulative pressure-drop of 0.003 bars and section 1 has a cumulative pressure-drop of 0.01 bars. This gives Kv values of 639.52m3/h and 342.39 respectively.

Step 3 – Use the Results in the Power Consumption Sheet

When all sections have their respective Kv vales assigned the results can be used in the power consumption sheet to calculate the potential savings.

Heat balance

Firstly, define all the consumers in the system and define their heat demand then the flow at maximum load. The template has 8 consumers, but more can be added by adding rows above the example consumer row, then copying the formulas from the row above. Make sure the pressure drop and flow is included in the sum below. The sum excludes the flow through the freshwater generator branch, since this has an external pump in the example calculation. The flow through the branch can be included by modifying the formula. Then define their status at each mode. This template has three modes, but more can be added as necessary.

Flow m3/h
-
-
-
66.20
-
0.29
-
-
=SUM(O9:O16)-O12

Figure 4 Formula for the flow through the central heating pump

Consumers:	Location:	Max Load (kW):	Maximum flow (m3/h)	Active	Capacity (%)
Bilage water separator	Branch 1	160	5.5	No	100%
Urea tank	Branch 2	25	1.8	No	100%
Bilage setling tank	Branch 3	18	1.5	No	100%
Fresh water evaporator	Branch 4	742.8	66.2	No	100%
AHU1 (ACC)	Main pipeline	489.5	21.5	Yes	17.5%
AHU2 (Wheelhouse)	Branch 5	44	1.94	Yes	34.0%
AHU3 (Galley)	Branch 6	90	3.96	Yes	17.5%
Example consumer		0	0		100.0%

Figure 3 All the consumers in the system with their capacity in harbor mode

Below row 19 the heat providers as well as the heat loss can be inserted. This calculation considers the heat that is required to all the consumers as well as the heat lost through the pipe and calculates what is required from the boiler. If there is enough heat from the heat recovery system this would be 0.

Heat providers and loss:							
Heatloss	Entire system	5			100%	5	1%
Heat recovery units	Main pipeline	2368		-	21%	497.28	99%
Oil fired boiler	Main pipeline					0	0%

Figure 5 Specification for where the heat is delivered, and the heat loss.

Fill out the consumption data table to calculate the potential for power savings. Under the distribution throughout the year the user can specify what percentage of the year this calculation will account for. For example, if this calculation is valid for May-August the percentage would be 33% of the year. Under the fuel emission data, the user can insert data from the emissions from fuel consumption. The data in the template is from the CAT3512C engine.

Consumption data		
Distrobution of year spent in these conditions [%]		37%
Average fuel price [kr/g]	NOK	0.018
Harbor		
Fuel consumption per [g/Kwh]		215.50
Distrobution spent in mode [%]		15%
Transit		
Fuel consumption per [g/Kwh]		202.80
Distrobution spent in mode [%]		3.5%
Dynamic positioning		
Fuel consumption per [g/Kwh]		203.25
Distrobution spent in mode [%]		81.5%

Fuel emission data	
Greenhouse gass	g/kg fuel
Co2	2918
Nox	29.65
Co	1.59
HC	0.92
Part matter	0.24

Figure 6 Screenshot from consumption and fuel emission data.

Pressure Calculation

In the pressure calculation tab is where the logic of which consumer is connected to which section. For example the flow through section 0 will be the sum of all consumers except the freshwater generator, the flow through section 2 will be the sum of all the air handling units and so on the formulas in the flow column can be copied over to the flow constant flow system column. Do this for all modes and insert the appropriate Kv value for each section. The sheet will then calculate the pressure drop in the main pipeline and the flow through the central heating pump. This will define the necessary working point in each mode.

			Pressure drop through main pipeline [m water colum]	0.482	15.190		Pressure drop through main pipeline [m water colum]	7.401	26.543
			Flow through central heating pump	5.1151	27.4		Flow through central heating pump	4.4398	27.4
		Harbor				Transit			
	Kv value [m3/h/bar]	Flow [m3/h]	Flow Constant flow system [m	Pressure drop in section [Bar]	Pressure drop Constant flowsystem [bar]	Flow [m3/h]	Flow Constant flow system [m3/	Pressure drop in section [Bar]	Pressure drop Constant flowsystem [bar]
Section 0	639.52	5.12	27.40	0.000	0.002	4.44	27.40	0.000	0.002
Section 1	342.39	5.12	27.40	0.000	0.006	4.44	27.40	0.000	0.006
Section 2	337.88	5.12	27.40	0.000	0.007	4.44	27.40	0.000	0.007
Section 9	112.99	5.12	27.40	0.002	0.059	4.44	27.40	0.002	0.059
Section 10	130.36	4.42	23.44	0.001	0.032	3.85	23.44	0.001	0.032
Section 11	20.43	3.76	21.50	0.034	1.107	3.23	21.50	0.025	1.107
Section 12	130.7	4.42	23.44	0.001	0.032	3.85	23.44	0.001	0.032
Section 13	110.45	5.12	27.40	0.002	0.062	4.44	27.40	0.002	0.062
Section 3	264.4	5.12	27.40	0.000	0.011	4.44	27.40	0.000	0.011
Section 4	113.33	5.12	27.40	0.002	0.058	4.44	27.40	0.002	0.058
Section 5	334.79	5.12	27.40	0.000	0.007	4.44	27.40	0.000	0.007
Section 6	624.11	5.12	27.40	0.000	0.002	4.44	27.40	0.000	0.002
Section 7	168.22	5.12	27.40	0.001	0.027	70.64	93.60	0.176	0.310
Section 8	98.24	5.12	27.40	0.003	0.078	70.64	93.60	0.517	0.908

Figure 7 Screenshot of the pressure calculation tab.

Find a Suitable Pump System

A dynamic system would most likely work at much lower flows than what the original system is designed for. It would therefore probably be beneficial to consider pumps that work well at lower flows and can still work at full capacity. This could be a single pump, or a parallel configuration of pumps. The power consumption template has multiple tabs where different pump configuration can be compared. This is done by estimating a second-degree polynomial for the pump curve and the efficiency curve as a function of the flow. This can be done with curve fitting software if the supplier cannot provide a function for the curve. (The efficiency should be a value between 0 and 1 not a percentage)

Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	33.5
b	0.01675
c	-0.00317

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	68
Minimum flow [m3/h]	4
Mimimum frequency [1/min]	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0271
f	-0.0003

Figure 8 Screenshot of the polynomials for Head and Efficiency.

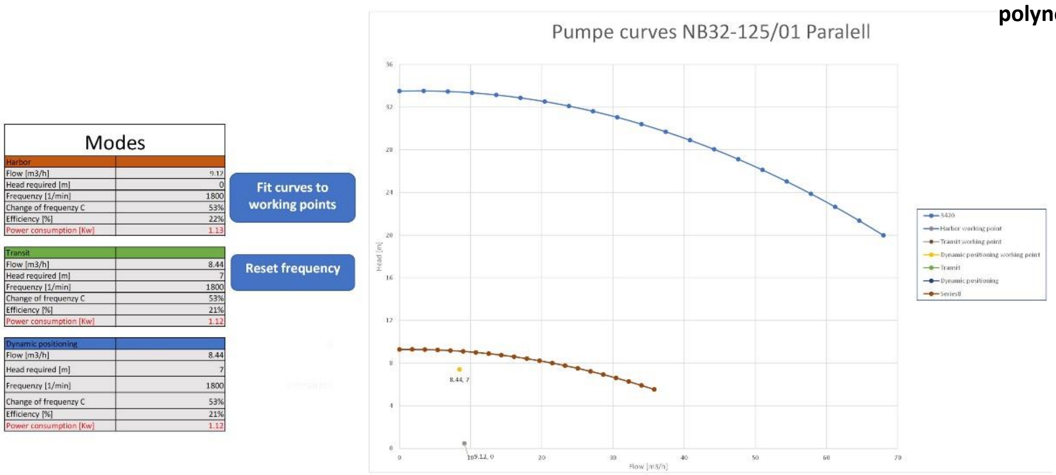


Figure 9 Illustration of fitting pump curve to working points.

The sheet will then extract values from the pressure calculation to consider how to pump preforms at that working point. In the constant flow system tab, the calculation is done with the assumption that the flow in each open branch is constant at the maximum capacity. In the other pump tabs the calculation is done with an assumption that the system is using throttling to limit the flow to whatever is necessary to deliver.

The sheet can consider power consumptions at a constant frequency, or it can fit the curve to each working point to simulate automatic frequency controlling. By pressing the fit curves to working points the sheet fits the curves so that they intersect the system curve at the lowest possible point. By pressing the reset frequency button, the curve is reset to the original frequency. This makes it possible to compare frequency controlling with just flow limiting by throttling.

Comparing the results of the calculation

When all the values above have been specified it is possible to compare results from the original system with different pump configurations. The "Fuel consumption" column compares the results from the most efficient pump with a dynamic system with the original pump. It then calculates the fuel costs for each system in each mode, and then the annual savings in both fuel and economical savings. These are the potential savings in the timeframe that is specified in the heat balance. Meaning that if the calculation is valid from May to August, then these are the potential savings during these months.

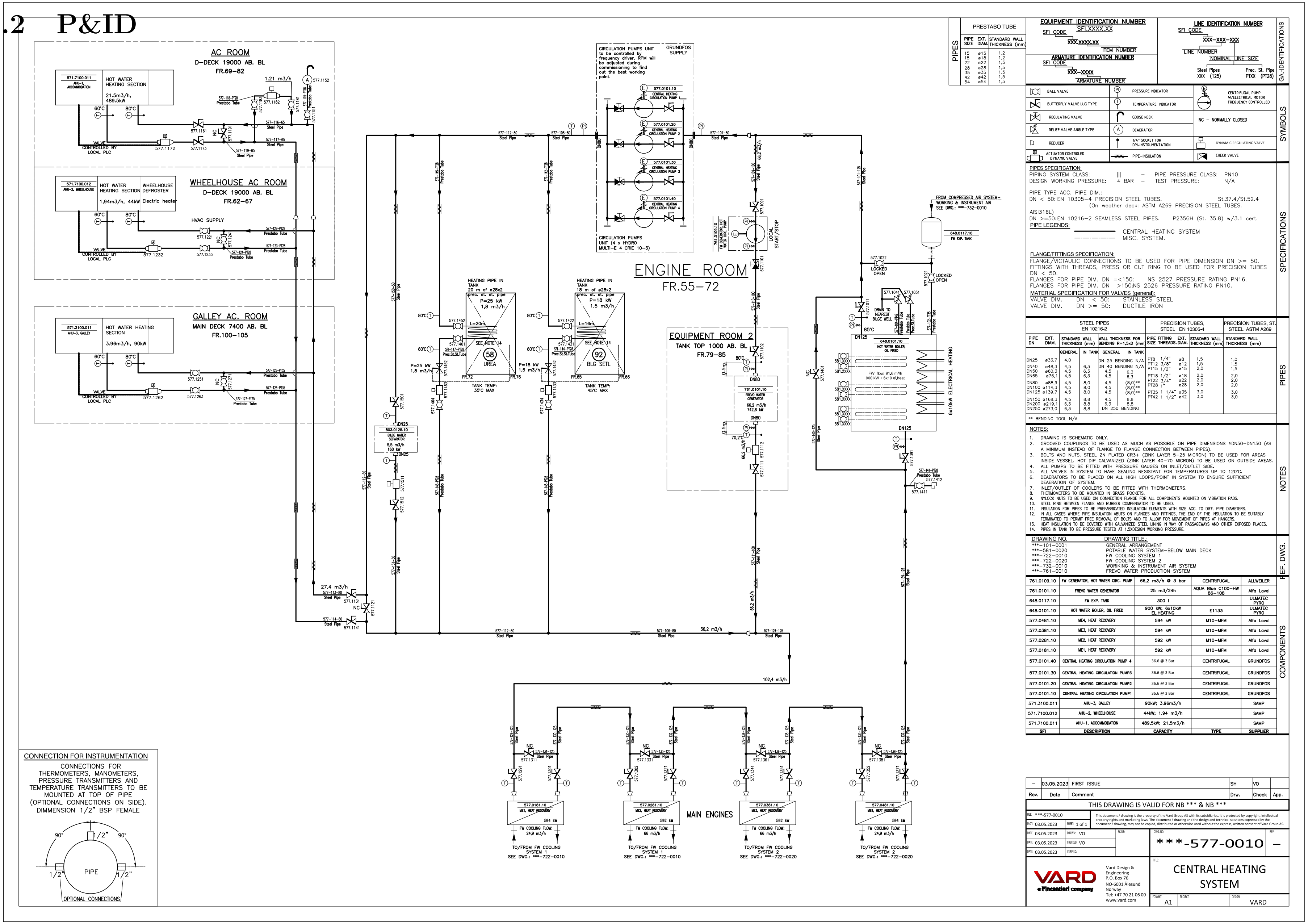
Fuel consumption		
Harbor		
Annual energy demand static [kWh]		2 138
Annual energy demand dynamic [kWh]		289
Fuel consumption static [kg]		460.8
Fuel consumption dynamic [kg]		62.3
Annual fuel cost static system	NOK	8 294
Annual fuel cost dynamic system	NOK	1 121
Annual savings	NOK	7 173
Transit		
Annual energy demand static [kWh]		499
Annual energy demand dynamic [kWh]		67
Fuel consumption static [kg]		101.2
Fuel consumption dynamic [kg]		13.6
Annual fuel cost static system	NOK	1 821
Annual fuel cost dynamic system	NOK	245
Annual savings	NOK	1 576
Dynamic positioning		
Annual energy demand static [kWh]		11 617
Annual energy demand dynamic [kWh]		1 562
Fuel consumption static [kg]		2361.2
Fuel consumption dynamic [kg]		317.5
Annual fuel cost static system	NOK	42 502
Annual fuel cost dynamic system	NOK	5 715
Annual savings	NOK	36 787
Average daily savings	NOK	337

Potential savings in emissions	
Annual Co2 emissions [kg]	7381.95
Annual Nox emissions [kg]	75.01
Annual Co emissions [kg]	4.02
Annual HC emissions [kg]	2.33
Annual part matter emissions [kg]	0.61

Figure 10 Screenshot of the potential for savings in fuel and emissions.

The potential savings in emissions column calculates how much this alternative system could save in greenhouse gas emissions, due to a lower fuel consumption. This is also in terms of the specified timeframe in heat balance.

A.2 P&ID


AC ROOM
D-DECK 19000 AB. BL
FR.69-82
WHEELHOUSE AC ROOM
D-DECK 19000 AB. BL
FR.62-67
GALLEY AC. ROOM
MAIN DECK 7400 AB. BL
FR.100-105
ENGINE ROOM
FR.55-72
EQUIPMENT ROOM 2
TANK TOP 1000 AB. BL
FR.79-85
MAIN ENGINES
CONNECTION FOR INSTRUMENTATION
CONNECTIONS FOR THERMOMETERS, MANOMETERS, PRESSURE TRANSMITTERS AND TEMPERATURE TRANSMITTERS TO BE MOUNTED AT TOP OF PIPE (OPTIONAL CONNECTIONS ON SIDE). DIMMENSION 1/2" BSP FEMALE
OPTIONAL CONNECTIONS
PIPE
GA-IDENTIFICATIONS
SYMBOLS
SPECIFICATIONS
PIPES
NOTES
REF. DWG.
COMPONENTS
THIS DRAWING IS VALID FOR NB *** & NB ***
03.05.2023 FIRST ISSUE
***-577-0010
CENTRAL HEATING SYSTEM
VARD
A1

A.3 System Description

***-577-001/002/003 CENTRAL HEATING SYSTEM

A central heating system includes:

- **Four** (4) off heat recovery units heat exchangers for main engines **(577.0181.10, 577.0281.10, 577.0381.10, 577.0481.10)**
- Fresh Water Evaporator heating **(761.0101.10)**
- Fresh Water Evaporator pump **(761.0109.10)**
- Bilge Water Separator **(803.0125.10)**
- Hot Water Boiler, Oil Fired **(648.0101.10)**
- Heating elements for air handling units serving the following areas /compartments:
    - Accommodation
    - Wheelhouse
    - Galley

The system consists of:

- Four (4) off Central Heating Circulation Pumps, frequency will be adjusted during commissioning to find out the best working point, (**577.0101.10, 577.0101.20, 577.0101.30, 577.0101.40**)
- Dynamic flow-regulating valves
- All hot water pipes are thermal insulated.

The main purpose of the system is to distribute heated water, produced in central heating system and heat recovery unit (exchangers) to heat consumers.

There are four pumps in the engine room, three in operation and one in backup. The pumps are automatically turned on or off to ensure optimal working conditions.

Return flow from all consumers goes through (4) Heat recovery units in the Engine room. The heat recovery units have a by-pass line on each side.

The flow to consumers are mainly controlled by remote operated dynamic flow regulation valves. Either with controller in IAS, HVAC Control System or self-operated. I addition there are a few constant flow consumers.

Different modes:

Harbour:

-One engine in use at 81% capacity. Specified to deliver 497KW of heat to the central heating system.

DP:

-All four engines in use at 73.1% capacity each. Specified to deliver maximum 1731KW of heat to the central heating system.

Transit:

-All four engines in use at 77.6% capacity each. Specified to deliver maximum 1838KW of heat to the central heating system.

A.4 Abstract of function

ABSTRACT OF FUNCTIONS

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			MACHINERY, SENSOR, TANK							FUNCTION					
REVISION	SFI NUMBER / ISA CODE (EQUIPMENT) MACHINERY, SENSOR, TANK	EQUIPMENT NAME / DESCRIPTION	HARDWIRE SIGNALS	MODBUS SIGNALS	EQUIPMENT QUANTITY	EQUIPMENT TYPE	POWER (kW)	SUPPLIER	IAS SIGNAL TYPE		IAS ALARM	IAS MIMIC	IAS CONTROL	AUTO CONTROL - IAS OR EXTERNAL	MACHINERY FUNCTIONAL DESCRIPTION OF EQUIPMENT	NOTES FROM IAS IO LIST

- REVISION: Item Revision
- SFI NUMBER / ISA CODE: Machinery SFI Number / ISA Code
- EQUIPMENT NAME / DESCRIPTION: Name and Description
- HARDWIRE SIGNALS / MODBUS SIGNALS: X = Interface to IAS is available.
- EQUIPMENT QUANTITY: Sensor / Equipment Quantity Number / Quantity of Equipment
- EQUIPMENT TYPE: **Sensor Type:** See Table 1
- POWER (kW): Power in kW of Equipment.
- SUPPLIER: **Sensor Supplier:** V = Vendor, VE = Vard Electro, VDE = Vard Electrical, VG = Vard Group, Y = Yard
- IAS SIGNAL TYPE: **Equipment with signal connected to IAS:** A = Analogue, D = Digital. Equipment with multiple signals to IAS: X = Ref. supplier document.
- IAS ALARM: **Alarm Presence and Type:** H = High, HH = High-High, L = Low, LL = Low-Low, X = Alarm Available
- IAS MIMIC: **Function on Mimic Console:** X = In IAS Mimic
- IAS CONTROL: Yes or No = Equipment Start/Stop from IAS.
- AUTO CONTROL - IAS OR EXTERNAL: IAS = Auto control from IAS. EXT. = Auto control from external sensor or equipment. YES = The equipment is used for Auto-Control.
- MACHINERY FUNCTIONAL DESCRIPTION OF EQUIPMENT: Functional decription of the equipment as it relates to the system. Listed by Machinery.

SENSOR/SIGNAL LIST - TABLE 1

BC	BREAKER CONTROL (Includes: close & open order, status, ready (BC+ also includes opened status))	SS	SPEED SWITCH
COS	CHANGE OVER SWITCH	ST	SPEED TRANSMITTER
DD	SMOKE DENISTY TRANSMITTER	TAT	TRIM ANGLE TRANSMITTER
DPS	DIFFERENTIAL PRESSURE SWITCH	TQ	TORQUE TRANSMITTER
DPT	DIFFERENTIAL PRESSURE TRANSMITTER	TR	THERMORESISTANCE
FRT	FREQUENCY TRANSMITTER	TS	TEMPERATURE SWITCH
FS	FLOW SWITCH	TT	TEMPERATURE TRANSMITTER
FT	FLOW TRANSMITTER (FLOWMETER)	TY	CALCULATED TEMEPERATURE VALUE
FI	FLOW INDICATION (FLOWMETER)	VC	REMOTE CONTROLLED VALVE (Includes: valve command, position, local/remote, alarm
HS	HUMIDITY SWITCH	VK	VISCOSITY CONTROL
IT	CURRENT TRANSMITTER	VOT	VOLTAGE TRANSMITTER
LAT	LIST ANGLE TRANSMITTER	VR	VALVE COMMAND (Includes: valve command, postion and local/remote)
LS	LEVEL SWITCH	VT	VISCOSITY TRANSMITTER
LI	LEVEL INDICATION	WD	WATER DETECTOR
MI	ELCTRONIC MOTOR INDICATION (Includes: running, failure (MI+ also includes: speed))	XS	CONTACT SWITCH (INTPUT)
MS	SINGLE SPEED ELECTRIC MOTOR CTRL (Includes: start, stop, running, available (cumulating remote and NOT failure))	XS^	CONTACT SWITCH (OUTTPUT)
MT	DOUBLE SPEED ELECTRIC MOTOR CTRL (Includes: start high/low, stop, running high/low, available (cumulating remote and NOT failure))	XT	TRANSMITTER (INPUT)
MV	VARIABLE SPEED ELECTRIC MOTOR CTRL (Includes: start, stop, running, speed control/speed feedback, by-pass, available (cumulating remote and NOT failure))	XT^	TRANSMITTER (OUTPUT)
OD	OIL DETECTOR	XT+	TEMP, PRESSURE REGULATOR (Includes: remote setpoint, actual value)
POT	POWER TRANSMITTER	ZSC	POSITION SWITCH FOR "CLOSED"
PS	PRESSURE SWITCH	ZSO	POSITION SWITCH FOR "OPENED"
PT	PRESSURE TRANSMITTER	ZT	POSITION TRANSMITTER
SD	SALINITY DETECTOR		

ABSTRACT OF FUNCTIONS

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ABSTRACT OF FUNCTIONS LIST DOC.NO:	***-577-0013	REVISION:	-	PIPING DIAGRAM DOC.NO:	***-577-0010
PREPARED DATE:	5/4/2023	REVISION DATE:	-	PIPING DIAGRAM TITLE:	CENTRAL HEATING SYSTEM
PREPARED BY:	VO	REVIEWED BY:	-	SYSTEM DESIGN PRESSURE:	3
DESIGN PROJECT NO:	-			YARD:	VARD
BUILD NO:	-			VESSEL TYPE:	-

REVISION	SFI NUMBER / ISA CODE (EQUIPMENT) MACHINERY, SENSOR, TANK	EQUIPMENT NAME / DESCRIPTION	MACHINERY, SENSOR, TANK: HARDWIRE SIGNALS	MODBUS SIGNALS	EQUIPMENT QUANTITY	EQUIPMENT TYPE	SUPPLIER	SIGNAL TYPE	FUNCTION:	IAS ALARM	IAS MIMIC	IAS CONTROL	IAS / EXT. AUTO CONTROL		FUNCTIONAL DESCRIPTION OF EQUIPMENT	NOTES FROM IAS IO LIST
	648.0101.10	HOT WATER BOILER, OIL FIRED	X	X	1	MI	V	X		X	X	NO	EXT		To be communicated acc.to suplier documentation	
	577.0101.10	CENTRAL HEATING CIRCULATION PUMP 1		X	1	MI	V	D		-	X	NO	EXT.		Regulation by dif.pressure in suction/discharge side	No Suction or Discharge Pressure for this pumps.
	577.0101.20	CENTRAL HEATING CIRCULATION PUMP 2		X	1	MI	V	D		-	X	NO	EXT.		Regulation by dif.pressure in suction/discharge side	No Suction or Discharge Pressure for this pumps.
	577.0101.30	CENTRAL HEATING CIRCULATION PUMP 3		X	1	MI	V	D		-	X	NO	EXT.		Regulation by dif.pressure in suction/discharge side	No Suction or Discharge Pressure for this pumps.
	577.0101.40	CENTRAL HEATING CIRCULATION PUMP 4		X	1	MI	V	D		-	X	NO	EXT.		Regulation by dif.pressure in suction/discharge side	No Suction or Discharge Pressure for this pumps.
	577.1421	BILGE SETLING Tk 92 regulating valve	-	-	1	TT	V			-	NO	No	EXT		Valve regulating by sensor in the tank 92	Not To or From IAS
	577.1451	UREA Tk 58 regulating valve	-	-	1	TT	V			-	NO	No	EXT		Valve regulating by sensor in the tank 58	Not To or From IAS
	577.1171	AHU-1 HEATING SECTION Actuator controlled dynamic valve	-	-	1	TT	Y			-	NO	No	EXT		Valve regulating by sensor at AHU-1	Not To or From IAS
	577.1231	AHU-2 HEATING SECTION Actuator controlled dynamic valve	-	-	1	TT	Y			-	NO	No	EXT		Valve regulating by sensor at AHU-2	Not To or From IAS
	577.1261	AHU-3 HEATING SECTION Actuator controlled dynamic valve	-	-	1	TT	Y			-	NO	No	EXT		Valve regulating by sensor at AHU-3	Not To or From IAS
	761.0109.10	FW GENERATOR, HOT WATER CIRC. PUMP	X	-	1					-	NO	No	-		Local start/stop	Not To or From IAS
	761.0101.10	FW GENERATOR	X		1	MI	V	X		X	X	No	EXT		To be communicated acc.to suplier documentation	

A.5 Armature list

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ARMATURE LIST

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ARMATURE LIST DOC.NO:	***-577-0011	REVISION:		PIPING DIAGRAM DOC.NO:	***-577-0010
REVISION DATE:				PIPING DIAGRAM TITLE:	CENTRAL HEATING SYSTEM
MADE BY:	SH			SYSTEM DESIGN PRESSURE:	3 BAR
DESIGN PROJECT NO:	XXX ***			YARD:	BRATTVÅG
BUILD NO:	***			VESSEL TYPE:	

SIGNS ACC. TO VARD STANDARD:

Type	Dimensions	Text size	Typical valves
1	74x8 mm	3,5 mm	Ball valves ≤ 3/4"
2	Ø40/6 mm	3,5 mm	Threaded globe valves
3	Ø50/15 mm	5,0 mm	Flanged globe valves
4	85x10 mm	5,0 mm	Ball valves ≥ 1" Other valves ≤ DN65
5	100x15 mm	5,0 mm	NR valves ≥ DN80 Butterfly valves ≥ DN80

TO BE COMPLETED BY THE YARD					ARMATURE INFO FROM VARD PIPE STANDARD										TO BE COMPLETED BY THE YARD	
TAG	ACTUATOR TAG	P.O. NUMBER	SUPPLIER	DESTINATION (YARD)	SFI	DESCRIPTION	SIZE	CONNECTION	PRESSURE RATING	HOUSING /BODY	TYPE	PIPE CLASS	CLASS CERTIFICATE	REMARKS	SIGN TYPE	SIGN TEXT
HNL02803		**660112**	BD	BRAILA	577.1021	Ball valve	1 1/4"	Threaded	PN100	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1021 TO FW EXP. TANK
HNL02804		**660112**	BD	BRAILA	577.1022	Ball valve	1 1/4"	Threaded	PN100	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1022 FROM FW EXP. TANK
HNL02805		**660112**	BD	BRAILA	577.1151	Ball valve	1/2"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		1	577.1151 TO AUTO. AIR VAL. DEAERATOR
HNL02807		**660112**	BD	BRAILA	577.1221	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1221 TO AHU-2 WHEELHOUSE
HNL02808		**660112**	BD	BRAILA	577.1233	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1233 FROM AHU-2 WHEELHOUSE
HNL02809		**660112**	BD	BRAILA	577.1241	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1241 CONNECT LINE 122 AND 123
HNL02810		**660112**	BD	BRAILA	577.1251	Ball valve	1 1/2"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1251 TO AHU-3 GALLEY
HNL02811		**660112**	BD	BRAILA	577.1263	Ball valve	1 1/2"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1263 FROM AHU-3 GALLEY
HNL02812		**660112**	BD	BRAILA	577.1271	Ball valve	1 1/2"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1271 CONNECT LINE 125 AND 126
HNL02813		**660112**	BD	BRAILA	577.1411	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1411 TO HOSE COUPLING
HNL02815		**660112**	BD	BRAILA	577.1422	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1422 TO BLG SETL TANK 92
HNL02816		**660112**	BD	BRAILA	577.1431	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1431 FROM BLG SETL TANK 92
RKL44604			From stock	BRATTVÅG	577.1434	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1434 FROM UREA TANK 58
HNL02818		**660112**	BD	BRAILA	577.1452	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1452 TO UREA TANK 58
		660112	BD		577.1183	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2007	Class III	N.A.		4	577.1183 FROM BLEED VALVE 577.1182
		660112	BD		577.1181	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2007	Class III	N.A.		4	577.1183 TO BLEED VALVE 577.1182
		VARD ACC scope	VARD ACC scope		577.1182	Dynamic regulating valve	1"	Threaded	PN16	DZR Brass	Frese Sigma Compact	Class III	N.A.	Flow Q = 1,21 m3/h	4	577.1182 BLEED FROM LINE 116 TO 117
HNL02819		**660112**	BD	BRAILA	577.1461	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1461 FROM UREA TANK 58
RKL44605			From stock	BRATTVÅG	577.1464	Ball valve	1"	Threaded	PN150	A351-CF8M	Haitima 2006	Class III	N.A.		4	577.1464 FROM BLG SETL TANK 92
HNL02253		**660112**	BD	BRAILA	577.1011	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1011 FROM HOT WATER BOILER, OIL FIRED
HNL02254		**660112**	BD	BRAILA	577.1091	Butterfly valve	DN100	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1091 TO FW GENERATOR, HOT WATER CIRC. PUMP
HNL02256		**660112**	BD	BRAILA	577.1102	Butterfly valve	DN100	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1102 TO FRESH WATER GENERATOR
HNL02257		**660112**	BD	BRAILA	577.1111	Butterfly valve	DN100	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1111 FROM FRESH WATER GENERATOR
HNL02258		**660112**	BD	BRAILA	577.1121	Butterfly valve	DN80	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1121 FROM CENTRAL HEATING CIRCULATION PUMP
HNL02259		**660112**	BD	BRAILA	577.1131	Butterfly valve	DN80	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1131 FROM CENTRAL HEATING CIRCULATION PUMP
HNL02260		**660112**	BD	BRAILA	577.1141	Butterfly valve	DN80	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1141 FROM CENTRAL HEATING CIRCULATION PUMP
HNL02261		**660112**	BD	BRAILA	577.1161	Butterfly valve	DN65	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1161 TO AHU-1 ACCOMMADATION
HNL02262		**660112**	BD	BRAILA	577.1173	Butterfly valve	DN65	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1173 FROM AHU-1 ACCOMMADATION
HNL02263		**660112**	BD	BRAILA	577.1181	Butterfly valve	DN65	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1181 CONNECT LINE 116 AND 117
HNL02264		**660112**	BD	BRAILA	577.1291	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1291 TO ME1, HEAT RECOVERY
HNL02265		**660112**	BD	BRAILA	577.1301	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1301 FROM ME1, HEAT RECOVERY
HNL02266		**660112**	BD	BRAILA	577.1302	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1302 TO ME2, HEAT RECOVERY
HNL02267		**660112**	BD	BRAILA	577.1311	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1311 ME1, HEAT RECOVERY BYPASS
HNL02268		**660112**	BD	BRAILA	577.1321	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1321 FROM ME2, HEAT RECOVERY
HNL02269		**660112**	BD	BRAILA	577.1331	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1331 ME2, HEAT RECOVERY BYPASS
HNL02270		**660112**	BD	BRAILA	577.1341	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1341 TO ME3, HEAT RECOVERY
HNL02271		**660112**	BD	BRAILA	577.1351	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1351 FROM ME3, HEAT RECOVERY
HNL02272		**660112**	BD	BRAILA	577.1352	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1352 TO ME4, HEAT RECOVERY
HNL02273		**660112**	BD	BRAILA	577.1361	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1361 ME3, HEAT RECOVERY BYPASS
HNL02274		**660112**	BD	BRAILA	577.1371	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1371 FROM ME4, HEAT RECOVERY
HNL02275		**660112**	BD	BRAILA	577.1381	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1381 ME4, HEAT RECOVERY BYPASS
HNL02276		**660112**	BD	BRAILA	577.1391	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1391 TO HOT WATER BOILER, OIL FIRED
HNL02277		**660112**	BD	BRAILA	577.1401	Butterfly valve	DN125	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1401 BYPASS HOT WATER BOILER, OIL FIRED
HNL02278		**660112**	BD	BRAILA	577.1501	Butterfly valve	DN50	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	5	577.1501 TO BW SEPARATOR
HNL02279		**660112**	BD	BRAILA	577.1512	Butterfly valve	DN50	Lug	PN16	Ductile iron	EGO (EPDM)	Class III	N.A.	Type B = Lever operated	4	577.1512 FROM BW SEPARATOR
HNL02806		**660112**	BD	BRAILA	577.1152	Deaerator	1/2"	Threaded	PN10	Bronze	Flamco Flexvent Super	Class III	N.A.			577.1152 AUTO. AIR VAL. DEAERATOR
HNL02606		662969	FRESE	BRAILA	577.1112	Dynamic regulating valve	DN100	Flanged	PN16	GJL-250	Frese SIGMA Compact	Class III	N.A.	Flow Q = 66,2 m3/h	5	577.1112 FROM FRESH WATER GENERATOR
		VARD ACC scope	VARD ACC scope	BRAILA	577.1172	Dynamic regulating valve	DN65	Flanged	PN16	GJL-250	Frese Optima Compact	Class III	N.A.	Flow Q = 19.65 m3/h	4	577.1172 FROM AHU-1 ACCOMMADATION
		VARD ACC scope	VARD ACC scope	BRATTVÅG	577.1232	Dynamic regulating valve	1"	Threaded	PN16	DZR Brass	Frese Optima Compact	Class III	N.A.	Flow Q = 1,94 m3/h	4	577.1232 FROM AHU-2 WHEELHOUSE
		VARD ACC scope	VARD ACC scope	BRATTVÅG	577.1262	Dynamic regulating valve	1 1/4"	Threaded	PN16	DZR Brass	Frese Optima Compact	Class III	N.A.	Flow Q = 3.96 m3/h	4	577.1262 FROM AHU-3 GALLEY
HNL05016		690892	FRESE	BRATTVÅG	577.1433	Dynamic regulating valve	1"	Threaded	PN16	DZR Brass	Frese SIGMA Compact	Class III	N.A.	Flow Q = 1,5 m3/h	No Sign	577.1433
HNL05017		690892	FRESE	BRATTVÅG	577.1463	Dynamic regulating valve	1"	Threaded	PN16	DZR Brass	Frese SIGMA Compact	Class III	N.A.	Flow Q = 1,8 m3/h	No Sign	577.1463
HNL02607		662969	FRESE	BRAILA	577.1511	Dynamic regulating valve	DN50	Flanged	PN16	GJL-250	Frese SIGMA Compact	Class III	N.A.	Flow Q = 5,5 m3/h	5	577.1511 FROM BW SEPARATOR
			YARD	BRATTVÅG	577.1412	Hose coupling	1"	Female end	PN16	Ca.Ir.	Camlock	Class III	N.A.		No Sign	577.1412 HOSE COUPLING
HNL02255		**660112**	BD	BRAILA	577.1101	NR valve closable	DN100	Flanged	PN16	Cast iron	Fig.10.159.SD	Class III	N.A.	Straight type with spring	5	577.1101 FROM FW GENERATOR, HOT WATER CIRC. PUMP
			ULMATEC PYRO	BRATTVÅG	577.1031	Pressure relief valve	1 1/4"	Threaded	PN10			Class III	N.A.	Ulmatec Pyro delivery	4	577.1031 DRAIN TO NEAREST BILGE WELL
			ULMATEC PYRO	BRATTVÅG	577.1041	Pressure relief valve	1 1/4"	Threaded	PN10			Class III	N.A.	Ulmatec Pyro delivery	4	577.1041 DRAIN TO NEAREST BILGE WELL
HNL02814		**660112**	BD	BRAILA	577.1432	Self acting temp.control valve	1"	Threaded	PN16		Danfoss AVTB	Class III	N.A.	Sensor Max temp. 45oC, Stainless steel pockets for un	No Sign	577.1432 From BLG SETL TANK 92
HNL02817		**660112**	BD	BRAILA	577.1462	Self acting temp.control valve	1"	Threaded	PN16		Danfoss AVTB	Class III	N.A.	Sensor Max temp. 35oC, Stainless steel pockets for un	No Sign	577.1462 FROM UREA TANK 58

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A.6 Pipe Dimensions and Heat Losses

Pipe dimensions and losses

Highest point of elevation.

	Unit	Section 0	Section 1	Section 2	Section 9	Section 10	Section 11	Section 11 Hot Side	Section 11 Cold Side
		Value	Value	Value	Value	Value	Value	Value	
Pipe diameter	mm	DN100	DN80	DN80	DN80	DN80	DN80	DN65	DN65
Inner diameter	mm	108.3	79.9	79.9	79.9	79.9	79.9	67.1	67.1
External diameter	mm	117.3	88.9	88.9	88.9	88.9	88.9	76.1	76.1
Bending radius	mm	175.95	133.35	133.35	133.35	133.35	133.35	114.15	114.15
Fluid temperature	c°	Hot side 80°C	Hot side 80°C	Hot side 80°C	Hot side 80°C	Hot side 80°C	Hot side 80°C	Hot side 80°C	Cold side 60°C
Flow	m3/h	36.2	36.2	27.4	27.4	23.44	21.5	21.5	21.5
Length of pipes	m	0.3	0.65	0.22	4.96	9	2.9	11.52	14.42
Bends	deg	65degx1	45degX1, 15degX1	Sharp bendX1	90degX2, Sharp bend X1, 50degX4	90degx2	90degX2	90degX8, 45degx10, 35degx3	
Other losses (enlargements, contractions etc)	deg	Contraction[100-80mm, 6deg]					Contraction[80-65mm, 5deg]	Butterfly valve kvs=188.5m3/h, AC Room AHU 1 (0.36 bar pressure drop) Elevation 15.5m, Butterfly valve, 3way valve(Kv_s=63m3/h), Sigma compact flenged DN 65 Standard high flow (0.33bar pressure drop),Enlarger[65-80mm, 5deg]	

	Section 11	Section 12	Section 13	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
	Value	Value	Value	Value	Value	Value	Value	Value	Value
Pipe diameter	DN80	DN80	DN80	DN80	DN80	DN80	DN80	DN125	DN125
Inner diameter	79.9	79.9	79.9	79.9	79.9	79.9	79.9	130.7	130.7
External diameter	88.9	88.9	88.9	88.9	88.9	88.9	88.9	139.7	139.7
Bending radius	133.35	133.35	133.35	133.35	133.35	133.35	133.35	209.55	209.55
Fluid temperature	Cold side 60°C	Cold side 60°C	Cold side 60°C	Cold side 60°C	Cold side 60°C	Cold side 60°C	Cold side 60°C	Hot side 80°C	Hot side 80°C
Flow	21.5	23.44	27.4	27.4	32.9	34.7	36.2	102.4	102.4
Length of pipes	3.09	8.94	4.83	1.08	7.3	0.53	0.28	18.5	7.65
Bends	90degX2	90degX2	90degX2, 45degX4, 70degX1, Sharp bendX1	50degX2	90degX5, 45degX2, 20degX1	90degX1	None	90degX12, Sharp bendX10, 25degX8, 30degX8, 15degX1	90degX6, 30degX1, 15degX1, sharp bendX1, Oil fired heater (can be modeled as a sharp bend)
Other losses (enlargements, contractions etc)			Butterfly valve Kv=258.8m3/h				Enlargement[80-125mm, 10deg]	Butterfly valve Kv=875.7m3/hx9, Heat exchangerX4 (0.24bar pressure drop)	Butterfly valve, lug type x1, Contraction[125-80mm, 11deg]

Heat loss calculation

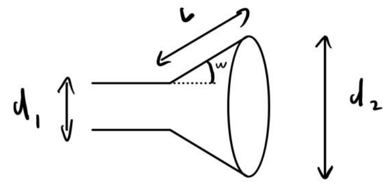
		Section 0	Section 1	Section 2	Section 9	Section 10	Section 11	Section 11 Hot Side	Section 11 Cold Side
Thickness of insulation	m	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Outer radius r2	m	0.09865	0.08445	0.08445	0.08445	0.08445	0.08445	0.07805	0.07805
Outer radius of pipe r1	m	0.05865	0.04445	0.04445	0.04445	0.04445	0.04445	0.03805	0.03805
Innter radius r0	m	0.05415	0.03995	0.03995	0.03995	0.03995	0.03995	0.03355	0.03355
Heat transfer rate k	w/m2k	0.793	0.751	0.751	0.751	0.751	0.751	0.727	0.727
Ao*k [w/k]	W/k	0.147	0.259	0.088	1.978	3.589	1.156	4.107	5.141
Cold side summary	w/k	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.141
Hot side summary	w/k	0.147	0.259	0.088	1.978	3.589	1.156	4.107	0.000

	Section 11	Section 12	Section 13	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8
Thickness of insulation	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.050	0.050
Outer radius r2	0.08445	0.08445	0.08445	0.08445	0.08445	0.08445	0.08445	0.11985	0.11985
Outer radius of pipe r1	0.04445	0.04445	0.04445	0.04445	0.04445	0.04445	0.04445	0.06985	0.06985
Innter radius r0	0.03995	0.03995	0.03995	0.03995	0.03995	0.03995	0.03995	0.06535	0.06535
Heat transfer rate k	0.751	0.751	0.751	0.751	0.751	0.751	0.751	0.633	0.633
Ao*k [w/k]	1.232	3.565	1.926	0.431	2.911	0.211	0.112	8.812	3.644
Cold side summary	1.232	3.565	1.926	0.431	2.911	0.211	0.112	0.000	0.000
Hot side summary	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.812	3.644

Reducer/enlarger degree calculator

Here is a calculator to find the angle of a reducer/enlarger. The value is required to be en degrees in sf pressure drop, however it is more accurate to measure the differance in diamters

	Unit	Value
Smaller diamter (d_1)	mm	80
Larger diamter (d_2)	mm	125
Length in between (L)	m	0.12
Angle (w)	deg	11



Pipe dimensions and losses

		Branch 1 Hot side	Branch 2 Cold side	Bilge water seperator
	Unit	Value		Value
Pipe diameter	mm	DN50	DN50	DN50
Inner diameter	mm	51.3	51.3	51.3
External diameter	mm	60.3	60.3	60.3
Bending radius	mm	90.45	90.45	90.45
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	5.5	5.5	5.5
Length of pipes	m	13.3	4.22	
Bends	deg	3x40deg, 7x90deg, 1x30deg, 2x45deg, 2x50deg, 1x35deg		
Other losses (enlargements, contractions etc)	deg	2xbutterfly valve Kv=115.7, 1xdynamic valve contraction (50-25mm, 9deg) enlargement (25-50mm, 9deg)		0.21bar pressure drop

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	0.030
Outer radius r2	m	0.06015	0.06015	0.06015
Outer radius of pipe r1	m	0.03015	0.03015	0.03015
Innter radius r0	m	0.02565	0.02565	0.02565
Heat transfer rate k	w/m2k	0.971	0.971	0.971
Ao*k [w/k]	W/k	4.883	1.549	0.000
Cold side summary	w/k	0.000	1.549	0.000
Hot side summary	w/k	4.883	0.000	0.000

Pipe dimensions and losses

		Branch 2 Hot side	Branch 2 Cold side	UREA Tank
	Unit	Value	Value	Value
Pipe diameter	mm	PT28	PT28	PT28
Inner diameter	mm	25	25	25
External diameter	mm	28	28	28
Bending radius	mm	42	42	42
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	1.8	1.8	1.8
Length of pipes	m	7	7	20
Bends	deg			90degX16, 60degX1, 45degX3
Other losses (enlargements, contractions etc)	deg	Ball valve x3 Selfacting temp. control valve x1 Dynamic regulating valve x1		

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	0.030
Outer radius r2	m	0.044	0.044	0.044
Outer radius of pipe r1	m	0.014	0.014	0.014
Innter radius r0	m	0.0125	0.0125	0.0125
Heat transfer rate k	w/m2k	0.806	0.806	0.806
Ao*k [w/k]	W/k	1.561	1.561	4.459
Cold side summary	w/k	0.000	1.561	0.000
Hot side summary	w/k	1.561	0.000	0.000

Pipe dimensions and losses

		Branch 3 Hot side	Branch Cold side	Bilage settle
	Unit	Value	Value	Value
Pipe diameter	mm	PT28	PT28	PT18
Inner diameter	mm	25	25	15.6
External diameter	mm	28	28	18
Bending radius	mm	42	42	27
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	1.5	1.5	1.5
Length of pipes	m	6	6	16
Bends	deg			90deg x23
Other losses (enlargements, contractions etc)	deg	Ball valve x3 Selfacting temp. control valve x1 Dynamic regulating valve x1		

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	0.030
Outer radius r2	m	0.044	0.044	0.039
Outer radius of pipe r1	m	0.014	0.014	0.009
Innter radius r0	m	0.0125	0.0125	0.0078
Heat transfer rate k	w/m2k	0.806	0.806	0.713
Ao*k [w/k]	W/k	1.338	1.338	2.797
Cold side summary	w/k	0.000	1.338	0.000
Hot side summary	w/k	1.338	0.000	0.000

Pipe dimensions and losses

		Branch 4 Hot side	Branch 4 Cold side	Fresh Water Generator
	Unit	Value		Value
Pipe diameter	mm	DN100	DN100	DN100
Inner diameter	mm	108.3	108.3	108.3
External diameter	mm	117.3	117.3	117.3
Bending radius	mm	175.95	175.95	175.95
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	66.2	67.2	66.2
Length of pipes	m	18.88	21.8	16
Bends	deg	14x90deg, 1x60deg, 1x45deg, 6x35deg, 2x25deg, 1x15deg, 1xSharp bend, 1xConnected pipe, 1xcheck valve, 1xdynamic valve, 3xbutterfly valve,		1x50deg, 1x90deg
Other losses (enlargements, contractions etc)	deg	Enlarger 80-100mm(6deg), Enlarger 100-125mm(6deg Contraction 100-80mm(6deg)		0.2bar pressure drop

Heat loss calculation				
Thickness of insulation	m	0.040	0.040	0.040
Outer radius r2	m	0.09865	0.09865	0.09865
Outer radius of pipe r1	m	0.05865	0.05865	0.05865
Innter radius r0	m	0.05415	0.05415	0.05415
Heat transfer rate k	w/m2k	0.793	0.793	0.793
Ao*k [w/k]	W/k	9.276	10.710	7.861
Cold side summary	w/k	0.000	10.710	0.000
Hot side summary	w/k	9.276	0.000	0.000

Pipe dimensions and losses

		Hot side	Cold side	Wheelhouse Room
	Unit	Value	Value	Value
Pipe diameter	mm	PT28	PT28	N/A
Inner diameter	mm	25	25	#N/A
External diameter	mm	28	28	#N/A
Bending radius	mm	42	42	#N/A
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Flow	m3/h	1.94	1.94	1.94
Length of pipes	m	17.5	17.5	
Bends	deg	Gjetter at det er rundt 90degX4, Inlet/outlet		AHU 2 har veldig liten flow og med stor sansynlighet små plastrør, jeg foreslår derfor å neglisjere trykkfallet som følge av røret og rørbøyer her siden de ikke er modellert.
Other losses (enlargements, contractions etc)	deg	3 way valve(0.06 bar pressure drop), dynamic valve DN25 High flow (0.2 bar pressure drop)		Pressure drop in AHU 2= 0.376 bar (K_vs=10m3/h)

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	
Outer radius r2	m	0.044	0.044	
Outer radius of pipe r1	m	0.014	0.014	
Innter radius r0	m	0.0125	0.0125	
Heat transfer rate k	w/m2k	0.806	0.806	
Ao*k [w/k]	W/k	3.902	3.902	
Cold side summary	w/k	0.000	3.902	0.000
Hot side summary	w/k	3.902	0.000	0.000

Pipe dimensions and losses

		Hot side	Cold side	Galley Room
	Unit	Value	Value	Value
Pipe diameter	mm	PT35	PT35	PT35
Inner diameter	mm	32	32	32
External diameter	mm	35	35	35
Bending radius	mm	52.5	52.5	52.5
Flow	m3/h	3.96	3.96	
Fluid temperature	c°	Hot side 80°C	Cold side 60°C	
Length of pipes	m	17.5	17.5	
Bends	deg	Gjetter at det er rundt 90degX4, Inlet/outlet		
Other losses (enlargements, contractions etc)	deg	3 way valve(0.05 bar pressure drop), dynamic valve DN32 (0.19 bar pressure drop)		AHU 3 pressure drop= 0.015bar K_vs=16m3/h)

Heat loss calculation				
Thickness of insulation	m	0.030	0.030	0.030
Outer radius r2	m	0.0475	0.0475	0.0475
Outer radius of pipe r1	m	0.0175	0.0175	0.0175
Innter radius r0	m	0.016	0.016	0.016
Heat transfer rate k	w/m2k	0.855	0.855	0.855
Ao*k [w/k]	W/k	4.466	4.466	
Cold side summary	w/k	0.000	4.466	0.000
Hot side summary	w/k	4.466	0.000	0.000

Heatloss entire system	
Heat loss [W]	4956
Heat loss [kW]	4.96

Main pipeline	**A_o*k [w/k]**	**Outside temperature [°C]**	**Delta T [k]**	**Heat loss [w]**
Cold side	15.53	15	45	699
Hot side	23.78	15	65	1546

Branch 1	**A_o*k [w/k]**			
Cold side	1.55	15	45	70
Hot side	4.88	15	65	317

Branch 2	**A_o*k [w/k]**			
Cold side	1.56	15	45	70
Hot side	1.56	15	65	101

Branch 3	**A_o*k [w/k]**			
Cold side	1.34	15	45	60
Hot side	1.34	15	65	87

Branch 4	**A_o*k [w/k]**			
Cold side	10.71	15	45	482
Hot side	9.28	15	65	603

AHU2	**A_o*k [w/k]**			
Cold side	3.90	15	45	176
Hot side	3.90	15	65	254

AHU3	**A_o*k [w/k]**			
Cold side	4.47	15	45	201
Hot side	4.47	15	65	290

A.7 SF Pressure Drop Calculation

Project:		Section 0			Section 1			Section 2		Section 9					Section 10	
Column nr.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Flow medium																
Flow medium		Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	36.2	36.2	36.2	36.2	36.2	36.2	27.4	27.4	27.4	27.4	27.4	27.4	27.4	23.44	23.44
Mass flow	kg/h	36134.84	36134.84	36134.84	36134.84	36134.84	36134.84	27350.68	27350.68	27350.68	27350.68	27350.68	27350.68	27350.68	23397.808	23397.808
Volume flow branch.pipe	m3/h															
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases																
Pressure (inlet, abs.)	bar															
Temperature (inlet)	°C															
Temperature (outlet)	°C															
Norm volume flow	Nm3/h															
3. Element of pipe																
Pipe identification		Section 0 Roughness	Section 0 bend	Section 0 Contraction	Section 1 Roughness	Section 1 45deg bend	Section 2 15deg bend	Section 2 Roughness	Sectin 2 sharp bend	Section 9 Roughness	Section 9 90deg bend	Section 9 50deg bend	Section 9 Sharp bend	Section 9 butterfly valve	Section 10 Roughness	Section 10 90deg bends
Element of pipe		circular	Circular bend	Gradual contraction	circular	Circular bend	Circular bend	circular	Sharp edged entrance	circular	Circular bend	Circular bend	Sharp edged entrance	Butterfly valve	circular	Circular bend
Number		1	1	1	1	1	1	1	1	1	2	4	1	1	1	2
Dimensions of element	SI	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D1: 108.30 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm
		Length of pipe L: 0.30 m	Radius R: 176.00 mm	Diameter of pipe D2: 78.90 mm	Length of pipe L: 0.65 m	Radius R: 133.35 mm	Radius R: 133.35 mm	Length of pipe L: 0.22 m		Length of pipe L: 4.96 m	Radius R: 133.35 mm	Radius R: 133.35 mm		Angle w: 0.00 degree	Length of pipe L: 9.00 m	Radius R: 133.35 mm
			Angle w: 65.00 degree	Angle w: 6.00 degree		Angle w: 45.00 degree	Angle w: 15.00 degree				Angle w: 90.00 degree	Angle w: 50.00 degree				Angle w: 90.00 degree
									The pipe entrance is: sharp-edged				The pipe entrance is: sharp-edged			
4. Result of calculation																
Veloc.of flow	m/s	1.091589313	1.091589313	1.091589313	2.005499831	2.005499831	2.005499831	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.298588841	1.298588841
Reynolds number		117770.7866	117770.7866	117770.7866	159631.742	159631.742	159631.742	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	103363.7578	103363.7578
Veloc.of flow 2	m/s			2.056658487												
Reynolds number 2				161654.958												
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm	0.2	0.2	0.2	0.2	0.2	0.2	0.2		0.2	0.2	0.2			0.2	0.2
Pipe friction number		0.024436658	0.024436658	0.024436658	0.025800866	0.025800866	0.025800866	0.026084513		0.026084513	0.026084513	0.026084513			0.026276338	0.026276338
Resistance coefficient		0.067691573	0.356569867	0.114503106	0.209894401	0.254236069	0.092710566	0.071822189	0.5	1.619263889	0.428511415	0.290625338	0.5	258.8 (kv value)	2.959787776	0.440809945
Resistance coefficient branch.pipe																
Press. drop branch.pipe	mbar															
Pressure drop	mbar	0.402569368	2.120560949	0.680962802	4.213409629	5.103522033	1.861067237	0.825991255	5.750251214	18.62234829	9.856193127	13.36934961	5.750251214	11.20914744	24.91101799	7.420143128
Pressure drop	bar	0.000402569	0.002120561	0.000680963	0.00421341	0.005103522	0.001861067	0.000825991	0.005750251	0.018622348	0.009856193	0.01336935	0.005750251	0.011209147	0.024911018	0.007420143
Sum Pressure drop	bar	0.000402569	0.00252313	0.003204093	0.007417503	0.012521025	0.014382092	0.015208083	0.020958334	0.039580683	0.049436876	0.062806226	0.068556477	0.079765624	0.104676642	0.112096785
5. Kv value																
Kv value for this node		0.003			0.01			0.01		0.06					0.03	
Kv value of section		639.52			342.39			337.88		112.99					130.36	

Section 10		Section 11													
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
23.44	23.44	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
23397.808	23397.808	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3	21461.3
998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
Section 10 Roughness	Section 10 90deg bends	Section 11 Roughness	Section 11 90deg bend	Section 11 Contraction	Section 11 Roughness DN65	Section 11 90deg bend	Section 11 45deg bends	Section 11 35deg bends	Section 11 enlargement	Section 11 butterfly valve (Manual calculation)	Section 11 AHU (Manual calculation)	Section 11 2-way valve (Manual calculation)	Section 11 Dynamic Valve (Calculation using Fresa quick calc)	Section 11 roughness DN80	Section 11 90deg bends
circular	Circular bend	circular	Circular bend	Gradual contraction	circular	Circular bend	Circular bend	Circular bend	Gradual enlargement	Butterfly valve	AHU1	2-way valve	Swing valve	circular	Circular bend
1	2	1	2	1	1	8	10	1	1	2	1	1	1	1	2
Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D1: 80.00 mm	Diameter of pipe D: 67.10 mm	Diameter of pipe D: 67.10 mm	Diameter of pipe D: 67.10 mm	Diameter of pipe D: 67.10 mm	Diameter of pipe D1: 65.00 mm	Diameter of pipe D: 65.00 mm	N/A	Diameter of pipe D: 65.00 mm	Diameter of pipe D: 65.00 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm
Length of pipe L: 9.00 m	Radius R: 133.35 mm	Length of pipe L: 2.90 m	Radius R: 133.35 mm	Diameter of pipe D2: 65.00 mm	Length of pipe L: 25.94 m	Radius R: 114.15 mm	Radius R: 114.15 mm	Radius R: 114.15 mm	Diameter of pipe D2: 80.00 mm	Angle w: 0.00 degree	N/A	Angle w: 0.00 degree	Angle w: 0.00 degree	Length of pipe L: 3.09 m	Radius R: 133.35 mm
	Angle w: 90.00 degree		Angle w: 90.00 degree	Angle w: 5.00 degree		Angle w: 90.00 degree	Angle w: 45.00 degree	Angle w: 35.00 degree	Angle w: 5.00 degree						Angle w: 90.00 degree
1.298588841	1.298588841	1.191111778	1.191111778	1.18813586	1.688888729	1.688888729	1.688888729	1.688888729	1.799779764	1.799779764	N/A	1.799779764	1.799779764	1.191111778	1.191111778
103363.7578	103363.7578	94808.90757	94808.90757	94690.39643	112894.6604	112894.6604	112894.6604	112894.6604	116542.0264	116542.0264	N/A	116542.0264	116542.0264	94808.90757	94808.90757
				1.799779764					1.18813586						
				116542.0264					94690.39643						
turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2					0.2	0.2
0.026276338	0.026276338	0.026394027	0.026394027	0.026388498	0.02725725	0.02725725	0.02725725	0.02725725	0.02743367					0.026394027	0.026394027
2.959787776	0.440809945	0.957980973	0.447888593	0.064944827	10.53730345	0.434566055	0.270652271	0.220871702	0.039460656	Kv=188.5		Kv=63m3/h	N/A	1.020745243	0.447888593
24.91101799	7.420143128	6.783432242	6.342969249	0.457577167	150.0096272	49.49204862	38.53020502	9.398858301	0.63795581	26.01862689	360	116.4651046	330	7.227864011	6.342969249
0.024911018	0.007420143	0.006783432	0.006342969	0.000457577	0.150009627	0.049492049	0.038530205	0.009398858	0.000637956	0.026018627	0.36	0.116465105	0.33	0.007227864	0.006342969
0.104676642	0.112096785	0.118880218	0.125223187	0.125680764	0.275690391	0.32518244	0.363712645	0.373111503	0.373749459	0.399768076	0.759768076	0.87623318	1.20623318	1.213461044	1.219804014
0.03		1.12													
130.36		20.43													

Section 12		Section 13						Section 3		Section 4				Section 5	
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
23.44	23.44	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	32.9	32.9	32.9	32.9	34.7	34.7
23397.808	23397.808	27350.68	27350.68	27350.68	27350.68	27350.68	27350.68	27350.68	27350.68	32840.78	32840.78	32840.78	32840.78	34637.54	34637.54
998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852

Section 12 Roughness	Section 12 90deg bends	Section 13 Roughness	Section 13 90deg bends	Section 13 45deg bends	Section 13 70deg bends	Section 13 sharp bend	Section 13 Butterfly Valve (Manual calculation)	Section 3 Roughness	Section 3 50degX2 bends	Section 4 Roughness	Section 4 90deg bends	Section 4 45deg bends	Section 4 20deg bends	Section 5 Roughness	Section 5 90deg bend
circular	Circular bend	circular	Circular bend	Circular bend	Circular bend	Sharp edged entrance	Swing valve	circular	Circular bend	circular	Circular bend	Circular bend	Circular bend	circular	Circular bend
1	2	1	2	4	1	1	1	1	2	1	5	2	1	1	1
Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm
Length of pipe L: 8.94 m	Radius R: 133.35 mm	Length of pipe L: 4.83 m	Radius R: 133.35 mm	Radius R: 133.35 mm	Radius R: 133.35 mm		Angle w: 0.00 degree	Length of pipe L: 1.08 m	Radius R: 133.35 mm	Length of pipe L: 7.30 m	Radius R: 133.35 mm	Radius R: 133.35 mm	Radius R: 133.35 mm	Length of pipe L: 0.53 m	Radius R: 133.35 mm
	Angle w: 90.00 degree		Angle w: 90.00 degree	Angle w: 45.00 degree	Angle w: 70.00 degree				Angle w: 50.00 degree		Angle w: 90.00 degree	Angle w: 45.00 degree	Angle w: 20.00 degree		Angle w: 90.00 degree

The pipe entrance is: sharp-edged

1.298588841	1.298588841	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.51797501	1.822678023	1.822678023	1.822678023	1.822678023	1.92239901	1.92239901
103363.7578	103363.7578	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	120826.2357	145079.6772	145079.6772	145079.6772	145079.6772	153017.1671	153017.1671
turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
0.2	0.2	0.2	0.2	0.2	0.2			0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.026276338	0.026276338	0.026084513	0.026084513	0.026084513	0.026084513			0.026084513	0.026084513	0.025890457	0.025890457	0.025890457	0.025890457	0.025839592	0.025839592
2.940055858	0.440809945	1.576823505	0.428511415	0.26739049	0.373280578	0.5	Kvs=258.8	0.352581653	0.290625338	2.365461055	0.414857695	0.258623381	0.125769809	0.171401546	0.411027488
24.74494453	7.420143128	18.13426255	9.856193127	12.30049991	4.292914195	5.750251214	11.20914744	4.05486616	6.684674806	39.2214176	34.39352102	8.576404682	2.085373672	3.161472241	7.581331808
0.024744945	0.007420143	0.018134263	0.009856193	0.0123005	0.004292914	0.005750251	0.011209147	0.004054866	0.006684675	0.039221418	0.034393521	0.008576405	0.002085374	0.003161472	0.007581332
1.244548958	1.251969101	1.270103364	1.279959557	1.292260057	1.296552971	1.302303222	1.31351237	1.317567236	1.324251911	1.363473328	1.397866849	1.406443254	1.408528628	1.4116901	1.419271432

0.03		0.06						0.01		0.08				0.01	
130.70		110.45						264.40		113.33				334.79	

Section 6		Section 7								Section 8								
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
36.2	36.2	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	36.2	36.2
36134.84	36134.84	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	102215.68	36134.84	36134.84
998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852

Section 6	Section 6 enlargement	Section 7 Roughness	Section 7 90deg bends	Section 7 25deg bends	Section 7 30deg bends	Section 7 15deg bends	Section 7 sharp bend	Section 7 Valve (manual calculation)	Section 7 Heat Recovery system (Manual Calculation)	Section 8 Roughness	Section 8 90deg bends	Section 8 30deg bends	Section 8 15deg bends	Section 8 sharp bend	Section 8 Butterfly Valve (Manual Calculation)	Section 8 Oil Fired Heater (Manual Calculation)	Section 9 Roughness	Section 9 Contraction
circular	Gradual enlargement	circular	Circular bend	Circular bend	Circular bend	Circular bend	Sharp edged entrance	Swing valve		circular	Circular bend	Circular bend	Circular bend	Sharp edged entrance	Butterfly valve	Sharp edged entrance	circular	Gradual contraction
1	1	1	12	8	8	1	1	9	4	1	6	1	1	1	1	1	1	1
Diameter of pipe D: 130.00 mm	Diameter of pipe D1: 79.90 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	N/A	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 130.70 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D1: 130.70 mm
Length of pipe L: 0.28 m	Diameter of pipe D2: 130.70 mm	Length of pipe L: 18.50 m	Radius R: 209.55 mm	Radius R: 209.55 mm	Radius R: 209.55 mm	Radius R: 209.55 mm		Angle w: 0.00 degree		Length of pipe L: 7.65 m	Radius R: 209.55 mm	Radius R: 209.55 mm	Radius R: 209.55 mm		Angle w: 0.00 degree		Length of pipe L: 0.25 m	Diameter of pipe D2: 79.90 mm
	Angle w: 10.00 degree		Angle w: 90.00 degree	Angle w: 25.00 degree	Angle w: 30.00 degree	Angle w: 15.00 degree					Angle w: 90.00 degree	Angle w: 30.00 degree	Angle w: 15.00 degree					Angle w: 11.00 degree

The pipe entrance is: sharp-edged | The pipe entrance is: sharp-edged | The pipe entrance is: sharp-edged

0.757581715	2.005499831	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	N/A	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	2.12010026	2.005499831	0.749488569
98112.12453	159631.742	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	N/A	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	276046.2368	159631.742	97586.65791
	0.749488569																	2.005499831
	97586.65791																	159631.742
turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
0.2	0.2	0.2	0.2	0.2	0.2	0.2				0.2	0.2	0.2	0.2				0.2	0.2
0.023859624	0.025800866	0.022600006	0.022600006	0.022600006	0.022600006	0.022600006				0.022600006	0.022600006	0.022600006	0.022600006				0.025800866	0.023845523
0.05138996	0.160260165	3.198929685	0.388767426	0.14695234	0.175395098	0.088882186	0.5	875 (K_v value)		1.322800654	0.388767426	0.175395098	0.088882186	0.5	875.7 (k_v value)	0.5	0.080728616	0.294293623
0.147205765	3.217054483	71.76373976	104.6577718	26.37344491	31.47804906	1.99395382	11.21683607	123.0641973	960	29.67527617	52.32888588	3.934756133	1.99395382	11.21683607	0.0136738	11.21683607	1.620542165	0.825084536
0.000147206	0.003217054	0.07176374	0.104657772	0.026373445	0.031478049	0.001993954	0.011216836	0.123064197	0.96	0.029675276	0.052328886	0.003934756	0.001993954	0.011216836	0.0136738	0.011216836	0.001620542	0.000825085
1.419418637	1.422635692	1.494399432	1.599057203	1.625430648	1.656908697	1.658902651	1.670119487	1.793183685	2.753183685	2.782858961	2.835187847	2.839122603	2.841116557	2.852333393	2.866007192	2.877224028	2.878844571	2.879669655

0.00		0.37							1.09									
624.11		168.22							98.24									

Project: Bilge water seperator		Pipe	Butterfly valve	Contraction	Enlargement	Dynamic valve	Bend	Bend	Bend	Bend	Bend	Bend	Connected pipes
Column nr.		1	2	3	4	5	6	7	8	9	10	11	10
1. Flow medium													
Flow medium		Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	27.4
Mass flow	kg/h	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	5490.1	27350.68
Volume flow branch.pipe	m3/h												5.5
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases													
Pressure (inlet, abs.)	bar												
Temperature (inlet)	°C												
Temperature (outlet)	°C												
Norm volume flow	Nm3/h												
3. Element of pipe													
Pipe identification		Branch 1, pipe	Branch 1, butterfly valve	Branch 1, contraction	Branch 1, enlargement	Branch 1, dynamic valve	Branch 1, bend	Branch 1, bend	Branch 1, bend	Branch 1, bend	Branch 1, bend	Branch 1, bend	Section 2, sharp bends pipe
Element of pipe		circular	Butterfly valve	Gradual contraction	Gradual enlargement	Dynamic valve flange, DN50	Circular bend	Circular bend	Circular bend	Circular bend	Circular bend	Circular bend	Branch flowing asunder
Number		1	2	1	1	1	3	7	1	2	2	1	1
Dimensions of element	SI	Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D1: 51.30 mm	Diameter of pipe D1: 25.70 mm		Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D: 51.30 mm	Diameter of pipe D1: 79.90 mm
		Length of pipe L: 17.52 m		Diameter of pipe D2: 25.70 mm	Diameter of pipe D2: 51.30 mm		Radius R: 90.45 mm	Radius R: 90.45 mm	Radius R: 90.45 mm	Radius R: 90.45 mm	Radius R: 90.45 mm	Radius R: 90.45 mm	Diameter of pipe D2: 51.30 mm
				Angle w: 9.00 degree	Angle w: 9.00 degree		Angle w: 40.00 degree	Angle w: 90.00 degree	Angle w: 30.00 degree	Angle w: 45.00 degree	Angle w: 50.00 degree	Angle w: 35.00 degree	Radius R: 0.00 mm
													Angle w: 90.00 degree
4. Result of calculation													
Veloc.of flow	m/s	0.739155099	0.739155099	0.739155099	2.945127227	0.739155099	0.739155099	0.739155099	0.739155099	0.739155099	0.739155099	0.739155099	1.51797501
Reynolds number		37774.85329	37774.85329	37774.85329	75402.72271	37774.85329	37774.85329	37774.85329	37774.85329	37774.85329	37774.85329	37774.85329	120826.2357
Veloc.of flow 2	m/s			2.945127227	0.739155099								0.739155099
Reynolds number 2				75402.72271	37774.85329								37774.85329
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm	0.2		0.2	0.2		0.2	0.2	0.2	0.2	0.2	0.2	
Pipe friction number		0.030873839		0.030873839	0.035759376		0.030873839	0.030873839	0.030873839	0.030873839	0.030873839	0.030873839	
Resistance coefficient		10.54404811	3.91	0.751090392	0.204808232	3.91	0.303464255	0.536346205	0.241009214	0.334691775	0.363773532	0.272236734	0.001179871
Resistance coefficient branch.pipe													0.952103526
Press. drop branch.pipe	mbar												10.94966891
Pressure drop	mbar	28.75187045		2.04809893	8.866313851		2.482490078	10.23769002	0.657192154	1.825297924	1.983900179	0.742344423	0.01356911
Pressure drop	bar	0.02875187	0.004519482	0.002048099	0.008866314	0.07	0.00248249	0.01023769	0.000657192	0.001825298	0.0019839	0.000742344	1.35691E-05
Sum Pressure drop	bar	0.02875187	0.033271352	0.035319451	0.044185765	0.114185765	0.116668255	0.126905945	0.127563137	0.129388435	0.131372336	0.13211468	0.132128249

Project: Urea tank		Ball valve	Self acting temp. control valve	Dynamic regualting valve	Pipe urea tank	Pipe	Bend, urea tank	Bend, urea tank	Bend, urea tank	Connected pipes
Column nr.		1	2	3	4	5	6	7	8	9
1. Flow medium										
Flow medium		Water	Water	Water	Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	27.4
Mass flow	kg/h	1796.76	1796.76	1796.76	1796.76	1796.76	1796.76	1796.76	1796.76	27350.68
Volume flow branch.pipe	m3/h									1.8
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases										
Pressure (inlet, abs.)	bar									
Temperature (inlet)	°C									
Temperature (outlet)	°C									
Norm volume flow	Nm3/h									
3. Element of pipe										
Pipe identification		Ball valve	Branch 2, self acting temp.control valve	Branch 2, dynamic regulating valve	Pipe urea tank	Pipe branch 2	Bend, urea tank	Bend, urea tank	Bend, urea tank	Section 2, sharp bends pipe
Element of pipe		Cock	Self acting temp. control valve	Dynamic regulating valve	circular	circular	Circular bend	Circular bend	Circular bend	Branch flowing asunder
Number		3	1	1	1	1	16	3	1	1
Dimensions of element	SI	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D1: 79.90 mm
		Angle w: 0.00 degree	Angle w: 0.00 degree	Angle w: 0.00 degree	Length of pipe L: 20.00 m	Length of pipe L: 14.00 m	Radius R: 42.00 mm	Radius R: 42.00 mm	Radius R: 42.00 mm	Diameter of pipe D2: 25.00 mm
							Angle w: 90.00 degree	Angle w: 45.00 degree	Angle w: 60.00 degree	Radius R: 0.00 mm
										Angle w: 90.00 degree
4. Result of calculation										
Veloc.of flow	m/s	1.018591636	1.018591636	1.018591636	1.018591636	1.018591636	1.018591636	1.018591636	1.018591636	1.51797501
Reynolds number		25368.21784	25368.21784	25368.21784	25368.21784	25368.21784	25368.21784	25368.21784	25368.21784	120826.2357
Veloc.of flow 2	m/s									1.018591636
Reynolds number 2										25368.21784
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm				0.15	0.15	0.15	0.15	0.15	
Pipe friction number					0.035091118	0.035091118	0.035091118	0.035091118	0.035091118	
Resistance coefficient		0			28.07289458	19.6510262	0.599595927	0.374603152	0.472122736	0.015422772
Resistance coefficient branch.pipe										1.284623435
Press. drop branch.pipe	mbar									14.77381494
Pressure drop	mbar	0	0		145.3700621	101.7590435	49.67826706	5.819430201	2.444796396	0.177369622
Pressure drop	bar	0	0.107890671	0.201	0.145370062	0.101759043	0.049678267	0.00581943	0.002444796	0.00017737
Sum Pressure drop	bar	0	0.107890671	0.308890671	0.454260733	0.556019776	0.605698043	0.611517474	0.61396227	0.61413964

Project: Bilge settle		Dynamic regulating valve	Self acting temp. control valve	Ball valve	Pipe	Pipe blg setl	Bends, blg setl	Connected pipes
Column nr.		1	2	3	4	5	6	12
1. Flow medium								
Flow medium		Water	Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	1.5	1.5	1.5	1.5	1.5	1.5	36.2
Mass flow	kg/h	1497.3	1497.3	1497.3	1497.3	1497.3	1497.3	36134.84
Volume flow branch.pipe	m3/h							1.5
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases								
Pressure (inlet, abs.)	bar							
Temperature (inlet)	°C							
Temperature (outlet)	°C							
Norm volume flow	Nm3/h							
3. Element of pipe								
Pipe identification		Branch 3m dynamic regulating valve	Branch 3, self acting temp. control valve	Branch 3, ball valve	Pipe, branch 3	Pipe, blg setl	Bends, blg setl.	Section 1, sharp bends pipe
Element of pipe		Dynamic regulating valve	Self acting temp. control valve	Ball valve	circular	circular	Circular bend	Branch flowing asunder
Number		1	1	3	1	1	23	1
Dimensions of element	SI	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D1: 79.90 mm
		Angle w: 0.00 degree	Angle w: 0.00 degree	Angle w: 0.00 degree	Length of pipe L: 11.70 m	Length of pipe L: 16.00 m	Radius R: 42.00 mm	Diameter of pipe D2: 25.00 mm
							Angle w: 90.00 degree	Radius R: 0.00 mm
								Angle w: 90.00 degree
4. Result of calculation								
Veloc.of flow	m/s	0.848826363	0.848826363	0.848826363	0.848826363	0.848826363	0.848826363	2.005499831
Reynolds number		21140.18153	21140.18153	21140.18153	21140.18153	21140.18153	21140.18153	159631.742
Veloc.of flow 2	m/s							0.848826363
Reynolds number 2								21140.18153
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm				0.15	0.15	0.15	
Pipe friction number					0.035622616	0.035622616	0.035622616	
Resistance coefficient				0	16.67138428	22.79847423	0.623804416	0.020222368
Resistance coefficient branch.pipe								1.122693341
Press. drop branch.pipe	mbar							22.53688955
Pressure drop	mbar			0	59.95107174	81.98437161	51.59428162	0.405942797
Pressure drop	bar	0.0171	0.074924077	0	0.059951072	0.081984372	0.051594282	0.000405943
Sum Pressure drop	bar	0.0171	0.092024077	0.092024077	0.151975149	0.23395952	0.285553802	0.285959745

Project: Fresh water generator								
Column nr.		1	2	3	4	5	6	7
1. Flow medium								
Flow medium		Water	Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	66.2	66.2	66.2	66.2	66.2	66.2	66.2
Mass flow	kg/h	66080.84	66080.84	66080.84	66080.84	66080.84	66080.84	66080.84
Volume flow branch.pipe	m3/h							
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases								
Pressure (inlet, abs.)	bar							
Temperature (inlet)	°C							
Temperature (outlet)	°C							
Norm volume flow	Nm3/h							
3. Element of pipe								
Pipe identification		Branch 4	Bend	Bend	Bend	Bend	Bend	Bend
Element of pipe		circular	Circular bend	Circular bend	Circular bend	Circular bend	Circular bend	Circular bend
Number		1	14	1	1	6	2	1
Dimensions of element	SI	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm
		Length of pipe L: 40.68 m	Radius R: 175.95 mm	Radius R: 175.95 mm	Radius R: 175.95 mm	Radius R: 175.95 mm	Radius R: 175.95 mm	Radius R: 175.95 mm
			Angle w: 90.00 degree	Angle w: 60.00 degree	Angle w: 45.00 degree	Angle w: 35.00 degree	Angle w: 25.00 degree	Angle w: 15.00 degree
4. Result of calculation								
Veloc.of flow	m/s	1.99622134	1.99622134	1.99622134	1.99622134	1.99622134	1.99622134	1.99622134
Reynolds number		215370.886	215370.886	215370.886	215370.886	215370.886	215370.886	215370.886
Veloc.of flow 2	m/s							
Reynolds number 2								
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pipe friction number		0.023780602	0.023780602	0.023780602	0.023780602	0.023780602	0.023780602	0.023780602
Resistance coefficient		8.932547374	0.390360724	0.307313371	0.243822346	0.198356804	0.147137909	0.088988839
Resistance coefficient branch.pipe								
Press. drop branch.pipe	mbar							
Pressure drop	mbar	177.6561663	108.6923826	6.112043185	4.849293431	23.67027539	5.85274407	1.769866453
Pressure drop	bar	0.177656166	0.108692383	0.006112043	0.004849293	0.023670275	0.005852744	0.001769866
Sum Pressure drop	bar	0.177656166	0.286348549	0.292460592	0.297309885	0.320980161	0.326832905	0.328602771

Project: Fresh water generator							
Column nr.		8	9	10	11	12	13
Flow medium		Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	66.2	102.4	66.2	66.2	66.2	66.2
Mass flow	kg/h	66080.84	102215.68	66080.84	66080.84	66080.84	66080.84
Volume flow branch.pipe	m3/h		66.2				
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
Pipe identification		Sharp bend	Connected pipe	Butterfly valve	Chech valve, Non return	Dynamic valve. Frese Sigma Compact Flanged	Enlargerment
Element of pipe		Sharp edged entrance	Branch flowing asunder	Butterfly valve	Check valve swing	Swing valve	Gradual enlargement
Number		1	1	3	1	1	1
Dimensions of element	SI	Diameter of pipe D: 108.30 mm	Diameter of pipe D1: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D: 108.30 mm	Diameter of pipe D1: 79.90 mm
			Diameter of pipe D2: 79.90 mm	Angle w: 0.00 degree		Angle w: 0.00 degree	Diameter of pipe D2: 108.30 mm
			Radius R: 0.00 mm				Angle w: 6.00 degree
			Angle w: 90.00 degree				
Veloc.of flow	m/s	1.99622134	3.087810653	1.99622134	1.99622134	1.99622134	3.667516266
Reynolds number		215370.886	333141.6726	215370.886	215370.886	215370.886	291923.241
Veloc.of flow 2	m/s		3.667516266				1.99622134
Reynolds number 2			291923.241				215370.886
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm						0.2
Pipe friction number							0.025383834
Resistance coefficient		0.5	0.10432045		1.858765284	0	0.060019928
Resistance coefficient branch.pipe			1.283542471				
Press. drop branch.pipe	mbar		61.08001514				
Pressure drop	mbar	9.944317051	4.964303712		36.96830261		4.029277146
Pressure drop	bar	0.009944317	0.004964304	0.016581384	0.036968303	0.52	0.004029277
Sum Pressure drop	bar	0.338547088	0.343511392	0.360092776	0.397061079	0.917061079	0.921090356

The pipe entrance is: sharp-edged

Project: Fresh water generator							
Column nr.		14	15	16	17	18	19
Flow medium		Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	66.2	66.2	66.2	66.2	66.2	66.2
Mass flow	kg/h	66080.84	66080.84	66080.84	66080.84	66080.84	66080.84
Volume flow branch.pipe	m3/h						
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
Pipe identification		Enlargerment	Contraction	Fresh water generator	Bend	Bend	Fresh water generator
Element of pipe		Gradual enlargement	Gradual contraction	circular	Circular bend	Circular bend	
Number		1	1	1	1	1	1
Dimensions of element	SI	Diameter of pipe D1: 108.30 mm	Diameter of pipe D1: 108.30 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	Diameter of pipe D: 79.90 mm	
		Diameter of pipe D2: 130.70 mm	Diameter of pipe D2: 79.90 mm	Length of pipe L: 16.00 m	Radius R: 133.35 mm	Radius R: 133.35 mm	
		Angle w: 6.00 degree	Angle w: 6.00 degree		Angle w: 90.00 degree	Angle w: 50.00 degree	
Veloc.of flow	m/s	1.99622134	1.99622134	3.667516266	3.667516266	3.667516266	
Reynolds number		215370.886	215370.886	291923.241	291923.241	291923.241	
Veloc.of flow 2	m/s	1.370611692	3.667516266				
Reynolds number 2		178459.5788	291923.241				
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	
Absolute roughness	mm	0.2	0.2	0.2	0.2	0.2	
Pipe friction number		0.023780602	0.023780602	0.025383834	0.025383834	0.025383834	
Resistance coefficient		0.03328834	0.104680923	5.083120664	0.391831186	0.265159918	
Resistance coefficient branch.pipe							
Press. drop branch.pipe	mbar						
Pressure drop	mbar	0.662059621	2.081960566	341.2416918	26.30453721	17.80080095	200
Pressure drop	bar	0.00066206	0.002081961	0.341241692	0.026304537	0.017800801	0.2
Sum Pressure drop	bar	0.921752415	0.923834376	1.265076068	1.291380605	1.309181406	1.509181406

Project: Weelhouse

Column nr.		1	2	3	4	5	6
1. Flow medium							
Flow medium		Water	Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	1.94	1.94	1.94	1.94	1.94	1.94
Mass flow	kg/h	1936.508	1936.508	1936.508	1936.508	1936.508	1936.508
Volume flow branch.pipe	m3/h						
Density	kg/m3	998.2	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases							
Pressure (inlet, abs.)	bar						
Temperature (inlet)	°C						
Temperature (outlet)	°C						
Norm volume flow	Nm3/h						
3. Element of pipe							
Pipe identification		Pipe, brach 5	Bends	Section 5 Inlet	Section 5 3-Way valve (Manual Calculation)	Section 5 Dynamic valve (Manual Calculation)	Section 5 AHU2 (Manual Calculation)
Element of pipe		circular	Circular bend	Sharp edged entrance	Swing valve	Swing valve	Air Handling Unit 2
Number		1	1	1	1	1	1
Dimensions of element	SI	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	Diameter of pipe D: 25.00 mm	
		Length of pipe L: 35.00 m	Radius R: 42.00 mm		Angle w: 0.00 degree	Angle w: 0.00 degree	
			Angle w: 90.00 degree				

The pipe entrance is: sharp-edged

4. Result of calculation							
Veloc.of flow	m/s	1.09781543	1.09781543	1.09781543	1.09781543	1.09781543	
Reynolds number		27341.30144	27341.30144	27341.30144	27341.30144	27341.30144	
Veloc.of flow 2	m/s						
Reynolds number 2							
Flow		turbulent	turbulent	turbulent	turbulent	turbulent	turbulent
Absolute roughness	mm	0.15	0.15				
Pipe friction number		0.034894417	0.034894417				
Resistance coefficient		48.85218363	0.590116387	0.5	0	0	Kvs=10m3/h
Resistance coefficient branch.pipe							
Press. drop branch.pipe	mbar						
Pressure drop	mbar	293.853056	3.549636696	3.0075734	60	200	376
Pressure drop	bar	0.293853056	0.003549637	0.003007573	0.06	0.2	0.376
Sum Pressure drop	bar	0.293853056	0.297402693	0.300410266	0.360410266	0.560410266	0.936410266

Project: Galley		Pipe	90 deg bend	Dynamic valve	3-way motor valve	AH3
Column nr.		1	2	3	4	
1. Flow medium						
Flow medium		Water	Water	Water	Water	Water
Condition		liquid	liquid	liquid	liquid	liquid
Volume flow	m3/h	3.96	3.96	3.96	3.96	3.96
Mass flow	kg/h	3952.872	3952.872	3952.872	3952.872	3952.872
Volume flow branch.pipe	m3/h					
Density	kg/m3	998.2	998.2	998.2	998.2	998.2
Dyn.Visvos.	10-6 kg/ms	1002	1002	1002	1002	1002
Kin.Viscos.	10-6 m2/s	1.003806852	1.003806852	1.003806852	1.003806852	1.003806852
2. Additional data for gases						
Pressure (inlet, abs.)	bar					
Temperature (inlet)	°C					
Temperature (outlet)	°C					
Norm volume flow	Nm3/h					
3. Element of pipe						
Pipe identification		Pipe, branch 6	Bend	Dynamic valve, Frese Sigma compact	3-way motor valve	AH3
Element of pipe		circular	Circular bend	Dynamic valve, Frese Sigma compact	3-way motor valve	AH3
Number		1	4	1	1	
Dimensions of element	SI	Diameter of pipe D: 32.00 mm	Diameter of pipe D: 32.00 mm	Diameter of pipe D: 32.00 mm	Diameter of pipe D: 32.00 mm	Diameter of pipe D: 32.00 mm
		Length of pipe L: 35.00 m	Radius R: 52.50 mm			
			Angle w: 90.00 degree			

4. Result of calculation						
Veloc.of flow	m/s	1.367737792	1.367737792	1.367737792	1.367737792	1.367737792
Reynolds number		43601.6244	43601.6244	43601.6244	43601.6244	43601.6244
Veloc.of flow 2	m/s					
Reynolds number 2						
Flow		turbulent	turbulent	turbulent	turbulent	
Absolute roughness	mm	0.15	0.15			
Pipe friction number		0.031878247	0.031878247			
Resistance coefficient		34.86683283	0.534489868	3.91	3.91	3.91
Resistance coefficient branch.pipe						
Press. drop branch.pipe	mbar					
Pressure drop	mbar	325.5410529	19.96147976			
Pressure drop	bar	0.325541053	0.01996148	0.19	0.05	0.015
Sum Pressure drop	bar	0.325541053	0.345502533	0.535502533	0.585502533	0.600502533

Branch	Cumulative Pressure drop (bar)	Flow m3/h
Main Pipeline	2.88	21.5
Branch 1	0.13	5.5
Branch 2	0.61	1.8
Branch 3	0.29	1.5
Branch 4	1.51	66.2
Branch 5	0.94	1.94
Branch 6	0.60	3.96

One or more of the Nodes has a more severe Pressure drop than the main pipeline

Column Comparison

Branch 1	
Inlet Column	6
Outlet Column	40
Pressure through main pipe (bar)	1.35
Pressure through branching pipe (bar)	0.13

Pressure through the main pipe has the most severe pressure drop

Branch 2	
Inlet Column	6
Outlet Column	44
Pressure through main pipe (bar)	1.40
Pressure through branching pipe (bar)	0.61

Pressure through the main pipe has the most severe pressure drop

Branch 3	
Inlet Column	6
Outlet Column	46
Pressure through main pipe (bar)	1.41
Pressure through branching pipe (bar)	0.29

Pressure through the main pipe has the most severe pressure drop

Branch 4		
Inlet Column	62	
Outlet Column	48	Caution, outlet node is before inlet node
Pressure through main pipe (bar)	1.50	
Pressure through branching pipe (bar)	1.51	

Pressure through the branching pipe has the most severe pressure drop

Branch 5	
Inlet Column	16
Outlet Column	30
Pressure through main pipe (bar)	1.13
Pressure through branching pipe (bar)	0.94

Pressure through the main pipe has the most severe pressure drop

Branch 6	
Inlet Column	14
Outlet Column	33
Pressure through main pipe (bar)	1.18
Pressure through branching pipe (bar)	0.60

Pressure through the main pipe has the most severe pressure drop

Column Comparison Tool

This is a tool to compare pressure through the main pipe and the pressure through each branching pipe. Select the inlet column in the dropdown menu, this is where the branch leaves the main pipeline.

Then proceed to select the outlet column, this is where the node returns. The tool then compares the pressure drop from the fluid traveling through the main pipeline and from traveling in the branch.

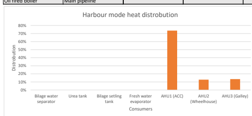
If the pressure in the main pipeline is most severe then the cumulative pressure drop from the main pipeline can be used.

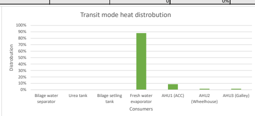
A.8 Power Consumption During Cold Conditions

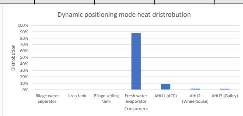
Central heating Balance Cold weather

				Harbor					
Consumers:	Location:	Max Load [kW]:	Maximum flow [m3/h]	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flowflow m3/h
Bilage water separator	Branch 1	160	5.5	No	100%	0	0%	-	-
Urea tank	Branch 2	25	1.8	No	100%	0	0%	-	-
Bilage setling tank	Branch 3	18	1.5	No	100%	0	0%	-	-
Fresh water evaporator	Branch 4	742.8	66.2	No	100%	0	0%	-	-
AHU1 (ACC)	Main pipeline	489.5	21.5	Yes	17.5%	85.6625	74%	3.76	21.50
AHU2 (Wheelhouse)	Branch 5	44	1.94	Yes	34.0%	14.96	13%	0.66	1.94
AHU3 (Galley)	Branch 6	90	3.96	Yes	17.5%	15.75	14%	0.69	3.96
Example consumer		0	0		100.0%	0	0%	-	-
							Flow through central heating pump [m3/h]	5.1	27.4
							Flow through FW	-	-
Heat providers and loss:									
Heatloss	Entire system	5			100%	5	1%		
Heat recovery units	Main pipeline	2368		-	21%	497.28	99%		
Oil fired boiler	Main pipeline					0	0%		

	Transit						Dynamic positioning					
Consumers:	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flowflow m3/h	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flowflow m3/h
Bilage water separator	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Urea tank	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Bilage setling tank	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Fresh water evaporator	Yes	100%	742.8	88%	66.20	66.20	Yes	100%	742.8	88%	66.20	66.20
AHU1 (ACC)	Yes	15.0%	73.425	9%	3.23	21.50	Yes	15.0%	73.425	9%	3.23	21.50
AHU2 (Wheelhouse)	Yes	32.0%	14.08	2%	0.62	1.94	Yes	32.0%	14.08	2%	0.62	1.94
AHU3 (Galley)	Yes	15.0%	13.5	2%	0.59	3.96	Yes	15.0%	13.5	2%	0.59	3.96
Example consumer		100.0%	0	0%	-	-		100.0%	0	0%	-	-
				Flow through central heating pump [m3/h]	4.4	27.4				Flow through central heating pump [m3/h]	4.4	27.4
				Flow through FW	66.20	66.20				Flow through FW	66.20	66.20
Heat providers and loss:												
Heatloss		100%	5	0%				100%	5	0%		
Heat recovery units	-	82%	1941.76	100%			-	82%	1941.76	100%		
Oil fired boiler			0	0%					0	0%		







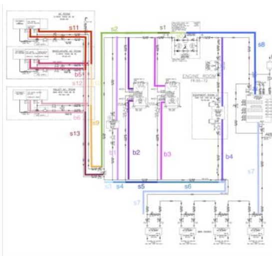
Consumption data		
Distrobution of year spent in these conditions [%]		37%
Average fuel price [kr/g]	NOK	0.018
Harbor		
Fuel consumption per [g/Kwh]		215.50
Distrobution spent in mode [%]		15%
Transit		
Fuel consumption per [g/Kwh]		202.80
Distrobution spent in mode [%]		3.5%
Dynamic positioning		
Fuel consumption per [g/Kwh]		203.25
Distrobution spent in mode [%]		81.5%

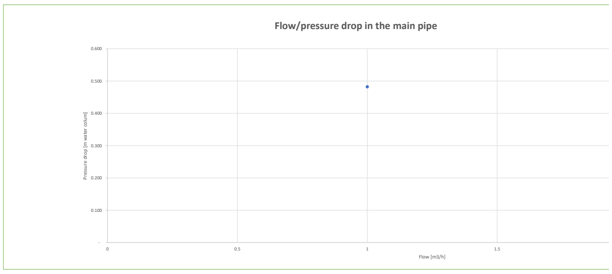
Fuel emission data	
Greenhouse gass	g/kg fuel
Co2	2918
Nox	29.65
Co	1.59
HC	0.92
Part matter	0.24

Harbor	Pressure drop through main pipeline [m water colum]	0.482	15.190			
Harbor	Flow through central heating pump	5.1151	27.4			
Transit	Pressure drop through main pipeline [m water colum]	7.401	26.543			
Transit	Flow through central heating pump	4.4398	27.4			
Dynamic positioning	Pressure drop through main pipeline [m water colum]	7.401	26.543			
Dynamic positioning	Flow through central heating pump	4.4398	27.4			

		Harbor				Transit				Dynamic positioning			
	Kv value [m3/h/bar]	Flow [m3/h]	Flow Constant flow system [m	Pressure drop in section [Bar]	Pressure drop Constant flowsystem [bar]	Flow [m3/h]	Flow Constant flow system [m3/	Pressure drop in section [Bar]	Pressure drop Constant flowsystem [bar]	Flow [m3/h]	Flow Constant flow system [m	Pressure drop in section [Bar]	Pressure drop Constant flowsystem [bar]
Section 0	639.52	5.12	27.40	0.000	0.002	4.44	27.40	0.000	0.002	4.44	27.40	0.000	0.002
Section 1	342.39	5.12	27.40	0.000	0.006	4.44	27.40	0.000	0.006	4.44	27.40	0.000	0.006
Section 2	337.88	5.12	27.40	0.000	0.007	4.44	27.40	0.000	0.007	4.44	27.40	0.000	0.007
Section 9	112.99	5.12	27.40	0.002	0.059	4.44	27.40	0.002	0.059	4.44	27.40	0.002	0.059
Section 10	130.36	4.42	23.44	0.001	0.032	3.85	23.44	0.001	0.032	3.85	23.44	0.001	0.032
Section 11	20.43	3.76	21.50	0.034	1.107	3.23	21.50	0.025	1.107	3.23	21.50	0.025	1.107
Section 12	130.7	4.42	23.44	0.001	0.032	3.85	23.44	0.001	0.032	3.85	23.44	0.001	0.032
Section 13	110.45	5.12	27.40	0.002	0.062	4.44	27.40	0.002	0.062	4.44	27.40	0.002	0.062
Section 3	264.4	5.12	27.40	0.000	0.011	4.44	27.40	0.000	0.011	4.44	27.40	0.000	0.011
Section 4	113.33	5.12	27.40	0.002	0.058	4.44	27.40	0.002	0.058	4.44	27.40	0.002	0.058
Section 5	334.79	5.12	27.40	0.000	0.007	4.44	27.40	0.000	0.007	4.44	27.40	0.000	0.007
Section 6	624.11	5.12	27.40	0.000	0.002	4.44	27.40	0.000	0.002	4.44	27.40	0.000	0.002
Section 7	168.22	5.12	27.40	0.001	0.027	70.64	93.60	0.176	0.310	70.64	93.60	0.176	0.310
Section 8	98.24	5.12	27.40	0.003	0.078	70.64	93.60	0.517	0.908	70.64	93.60	0.517	0.908

This calculates the pressure drop through the main pipe in each Mode. This is done by considering the pressure drop during full operation and assigning a Kv value to each branch. This is done with an assumption that the pressure drop in each section is proportional to the square of the flow. This is true as long as there are no dynamic valves restricting the flow, which is only in section 11. This flow is always constant regardless of the other brances, so the assumption is true.





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	33.5
b	0.118
c	-0.0174

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	32
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0535
f	-0.0012

Modes

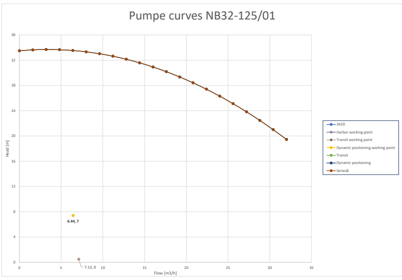
Harbor	
Flow [m3/h]	7.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	32%
Power consumption [Kw]	2.25

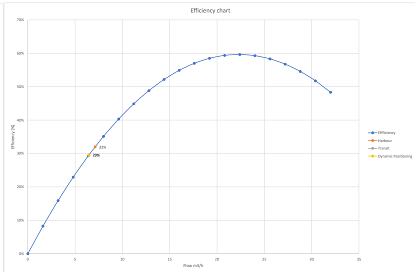
Transit	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	29%
Power consumption [Kw]	2.21

Dynamic positioning	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	29%
Power consumption [Kw]	2.21

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	33.5
b	0.01675
c	-0.00317

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	68
Minimum flow [m3/h]	4
Mimimum frequency [1/min]	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0271
f	-0.0003

Modes

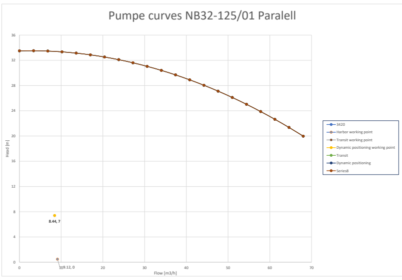
Harbor	
Flow [m3/h]	9.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	22%
Power consumption [Kw]	4.14

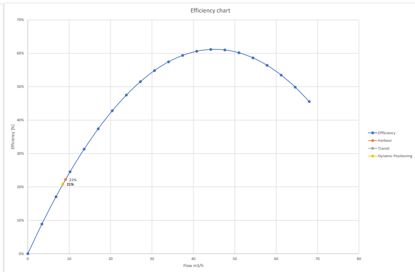
Transit	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11

Dynamic positioning	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	45
b	0.175
c	-0.015

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3600
Max flow at given frequenzy [m3/h]	48
Minumum flow [m3/h]	16
Mimimum frequency [1/min]	3513

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0441
f	-0.0007

Modes

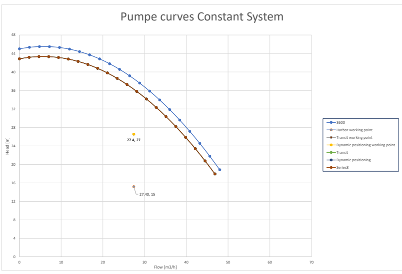
Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

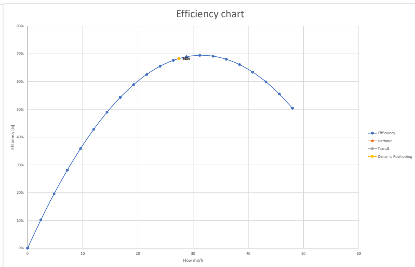
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Fit curves to working points

Reset frequency





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	33.5
b	0.01675
c	-0.00317

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	68
Minimum flow [m3/h]	4
Mimimum frequency [1/min]	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0271
f	-0.0003

Modes

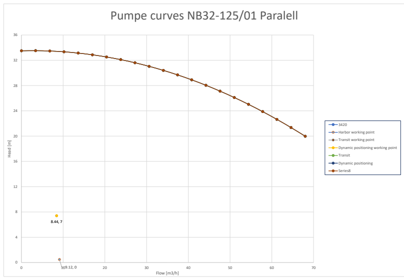
Harbor	
Flow [m3/h]	9.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	22%
Power consumption [Kw]	4.14

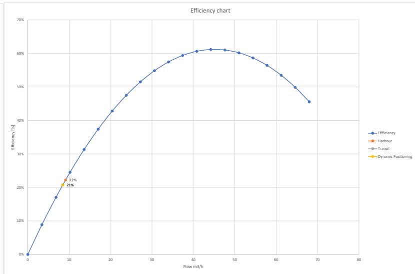
Transit	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11

Dynamic positioning	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11

Fit curves to working points

Reset frequency





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	43.8
b	0.8
c	-0.1321

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3000
Max flow at given frequenzy [m3/h]	16
Minimum flow [m3/h]	1.21
Minimum ffrequency [1/min]	1584

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.1361
f	-0.0072

Modes

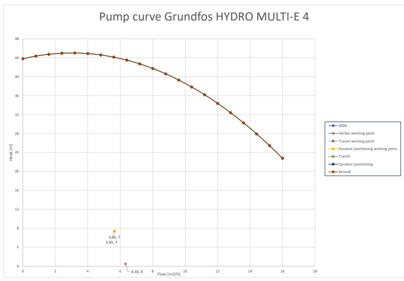
Harbor	
Flow [m3/h]	6.33
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	57%
Power consumption [Kw]	1.45

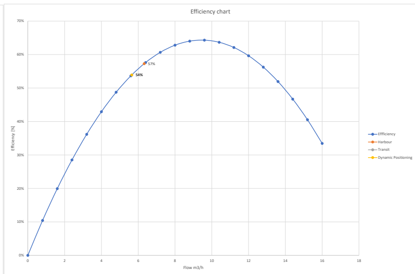
Transit	
Flow [m3/h]	5.65
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	54%
Power consumption [Kw]	1.40

Dynamic positioning	
Flow [m3/h]	5.65
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	54%
Power consumption [Kw]	1.40

Fit curves to working points

Reset frequency





Summary of the pump calculations cold weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	9.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	22%
Power consumption [Kw]	4.14
0	0
Transit	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11
0	0
Dynamic positioning	
Flow [m3/h]	8.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	21%
Power consumption [Kw]	4.11

NB 32 125/01

Harbor	
Flow [m3/h]	7.12
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	32%
Power consumption [Kw]	2.25
0	0
Transit	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	29%
Power consumption [Kw]	2.21
0	0
Dynamic positioning	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	29%
Power consumption [Kw]	2.21

NB 32-160/02

Harbor	
Flow [m3/h]	7.12
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	30%
Power consumption [Kw]	2.52
0	0
Transit	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	27%
Power consumption [Kw]	2.49
0	0
Dynamic positioning	
Flow [m3/h]	6.44
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	27%
Power consumption [Kw]	2.49

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Harbor	
Flow [m3/h]	6.33
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	57%
Power consumption [Kw]	1.45
0	0
Transit	
Flow [m3/h]	5.65
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	54%
Power consumption [Kw]	1.40
0	0
Dynamic positioning	
Flow [m3/h]	5.65
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	54%
Power consumption [Kw]	1.40

Constant flow system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.45
Power saving[Kw]	2.94
Power saving potential [%]	67%
Power consumption scaling factor [1]	0.33
Transit	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.40
Power saving[Kw]	3.00
Power saving potential [%]	68%
Power consumption scaling factor [1]	0.32
Dynamic positioning	
Power consumption with static system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.40
Power saving[Kw]	3.00
Power saving potential [%]	68%
Power consumption scaling factor [1]	0.32

Fuel consumption

Harbor		
Annual energy demand static [kWh]		2 138
Annual energy demand dynamic [kWh]		707
Fuel consumption static [kg]		460.8
Fuel consumption dynamic [kg]		152.3
Annual fuel cost static system	NOK	8 294
Annual fuel cost dynamic system	NOK	2 742
Annual savings	NOK	5 552
Transit		
Annual energy demand static [kWh]		499
Annual energy demand dynamic [kWh]		158
Fuel consumption static [kg]		101.2
Fuel consumption dynamic [kg]		32.1
Annual fuel cost static system	NOK	1 821
Annual fuel cost dynamic system	NOK	578
Annual savings	NOK	1 243
Dynamic positioning		
Annual energy demand static [kWh]		11 617
Annual energy demand dynamic [kWh]		3 689
Fuel consumption static [kg]		2361.2
Fuel consumption dynamic [kg]		749.8
Annual fuel cost static system	NOK	42 502
Annual fuel cost dynamic system	NOK	13 497
Annual savings	NOK	29 005

Average daily savings	NOK	265
Total annual savings	NOK	35 799
Total annual fuel saving [kg]		1988.9

Potential savings in emissions

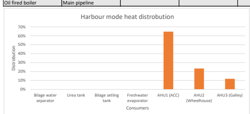
Annual Co2 emissions [kg]	5803.48
Annual Nox emissions [kg]	58.97
Annual Co emissions [kg]	3.16
Annual HC emissions [kg]	1.83
Annual part matter emissions [kg]	0.48

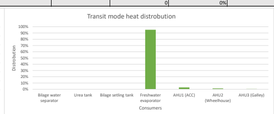
This is the potential for savings by swiching from a static flow system without throtteling to a dynamic flow system, either with frequency controllig or using just throttleing depending on the pump curves were fit the the working points or kept at a constant frequency.

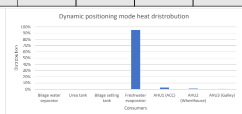
A.9 Power Consumption During Middle Conditions

Central heating Balance Middle weather

				Harbor						Transit						Dynamic positioning					
Consumers:	Location:	Max Load [kW]:	Maximum flow [m3/h]	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h	Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	Branch 1	160	5.5	No	100%	0	0%	-	-	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Urea tank	Branch 2	25	1.8	No	100%	0	0%	-	-	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Bilage setling tank	Branch 3	18	1.5	No	100%	0	0%	-	-	No	100%	0	0%	-	-	No	100%	0	0%	-	-
Freshwater evaporator	Branch 4	742.8	66.2	No	100%	0	0%	-	-	Yes	100%	742.8	95%	66.20	66.20	Yes	100%	742.8	95%	66.20	66.20
AHU1 (ACC)	Main pipeline	489.5	21.5	Yes	6.2%	30.349	65%	1.33	21.50	Yes	4.7%	23.0065	3%	1.01	21.50	Yes	4.7%	23.0065	3%	1.01	21.50
AHU2 (Wheelhouse)	Branch 5	44	1.94	Yes	25.0%	11	23%	0.49	1.94	Yes	23.7%	10.428	1%	0.46	1.94	Yes	23.7%	10.428	1%	0.46	1.94
AHU3 (Galley)	Branch 6	90	3.96	Yes	6.2%	5.58	12%	0.25	3.96	Yes	4.7%	4.23	1%	0.19	3.96	Yes	4.7%	4.23	1%	0.19	3.96
Example consumer		0	0		100.0%	0	0%	-	-		100.0%	0	0%	-	-		100.0%	0	0%	-	-
							Flow through central heating pump [m3/h]	2.1	27.4				Flow through central heating pump [m3/h]	1.7	27.4				Flow through central heating pump [m3/h]	1.7	27.4
							Flow through FW	-	-				Flow through FW	66.20	66.20				Flow through FW	66.20	66.20
Heat providers and loss:																					
Heatloss	Entire system	5			100%	5	1%				100%	5	0%				100%	5	0%		
Heat recovery units	Main pipeline	2368		-	21%	497.28	99%			-	82%	1941.76	100%			-	82%	1941.76	100%		
Oil fired boiler	Main pipeline					0	0%					0	0%					0	0%		





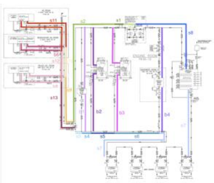


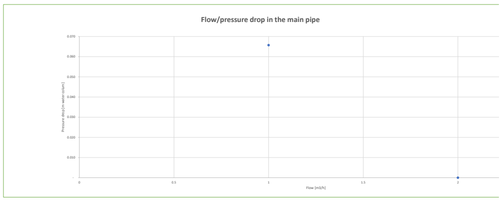
Consumption data		
Distrobution of year spent in these conditions [%]		24%
Average fuel price [kr/g]	NOK	0.018
Harbor		
Fuel consumption per [g/Kwh]		215.50
Distrobution spent in mode [%]		15%
Transit		
Fuel consumption per [g/Kwh]		202.80
Distrobution spent in mode [%]		3.5%
Dynamic positioning		
Fuel consumption per [g/Kwh]		203.25
Distrobution spent in mode [%]		81.5%

Fuel emission data	
Greenhouse gass	g/kg fuel
Co2	2918
Nox	29.65
Co	1.59
HC	0.92
Part matter	0.24

			Pressure drop through main pipeline [m water colum]	0.066	15.190		Pressure drop through main pipeline [m water colum]	6.561	26.043		Pressure drop through main pipeline [m water colum]	6.561	26.043
			Flow through central heating pump	2.06352	27.4		Flow through central heating pump	1.6564	27.4		Flow through central heating pump	1.6564	27.4
		Harbor				Transit				Dynamic positioning			
	Kv value [m3/h/bar]	Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]	Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]	Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]
Section 0	639.52	2.06	27.40	0.000	0.002	1.66	27.40	0.000	0.002	1.66	27.40	0.000	0.002
Section 1	341.16	2.06	27.40	0.000	0.006	1.66	27.40	0.000	0.006	1.66	27.40	0.000	0.006
Section 2	337.99	2.06	27.40	0.000	0.007	1.66	27.40	0.000	0.007	1.66	27.40	0.000	0.007
Section 9	112.99	2.06	27.40	0.000	0.009	1.66	27.40	0.000	0.009	1.66	27.40	0.000	0.009
Section 10	130.36	1.82	23.44	0.000	0.022	1.47	23.44	0.000	0.022	1.47	23.44	0.000	0.022
Section 11	20.43	1.33	21.50	0.004	1.107	1.01	21.50	0.002	1.107	1.01	21.50	0.002	1.107
Section 12	136.7	1.82	23.44	0.000	0.022	1.47	23.44	0.000	0.022	1.47	23.44	0.000	0.022
Section 13	110.43	2.06	27.40	0.000	0.002	1.66	27.40	0.000	0.002	1.66	27.40	0.000	0.002
Section 3	204.4	2.06	27.40	0.000	0.011	1.66	27.40	0.000	0.011	1.66	27.40	0.000	0.011
Section 4	113.03	2.06	27.40	0.000	0.018	1.66	27.40	0.000	0.018	1.66	27.40	0.000	0.018
Section 5	204.78	2.06	27.40	0.000	0.007	1.66	27.40	0.000	0.007	1.66	27.40	0.000	0.007
Section 6	624.11	2.06	27.40	0.000	0.002	1.66	27.40	0.000	0.002	1.66	27.40	0.000	0.002
Section 7	148.02	2.06	27.40	0.000	0.027	67.86	93.60	0.162	0.210	67.86	93.60	0.162	0.210
Section 8	98.16	2.06	27.40	0.000	0.078	67.86	93.60	0.477	0.908	67.86	93.60	0.477	0.908

This calculates the pressure drop through the main pipe in each Mode. This is done by considering the pressure drop during full operation and assigning a Kv value to each branch. This is done with an assumption that the pressure drop in each section is proportional to the square of the flow. This is true as long as there are no dynamic valves restricting the flow, which is only in section 11. This flow is always constant regardless of the other branches, so the assumption is true.





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	45
b	0.175
c	-0.015

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3600
Max flow at given frequenzy [m3/h]	48
Minumum flow [m3/h]	16
Mimimum frequency [1/min]	3513

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0441
f	-0.0007

Modes

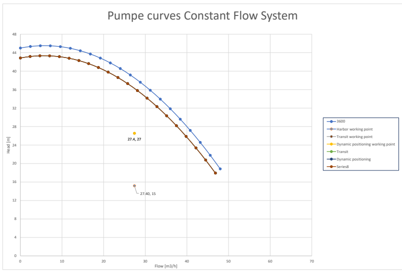
Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

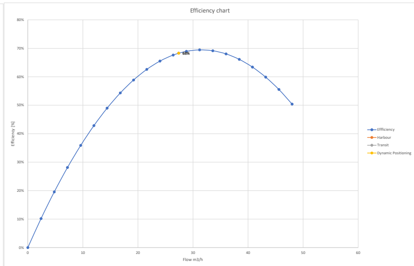
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Fit curves to working points

Reset frequency





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	33.5
b	0.118
c	-0.0174

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	32
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0535
f	-0.0012

Modes

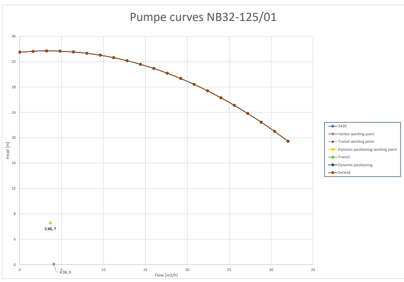
Harbor	
Flow [m3/h]	4.06
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	20%
Power consumption [Kw]	2.09

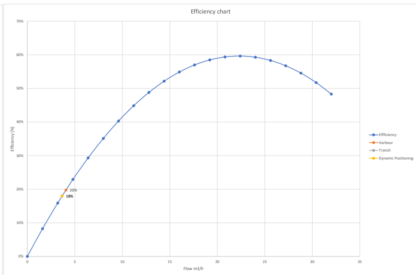
Transit	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07

Dynamic positioning	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07

Fit curves to working points

Reset frequency





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	33.5
b	0.118
c	-0.0174

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	32
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0535
f	-0.0012

Modes

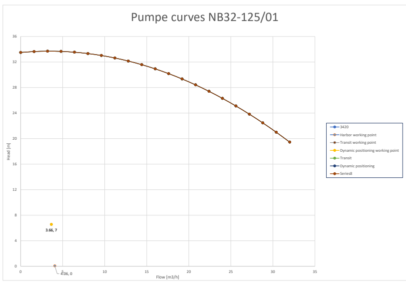
Harbor	
Flow [m3/h]	4.06
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	20%
Power consumption [Kw]	2.09

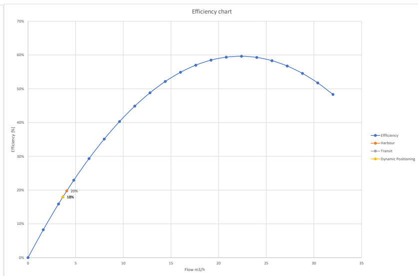
Transit	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07

Dynamic positioning	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	43.8
b	0.8
c	-0.1321

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3000
Max flow at given frequenzy [m3/h]	16
Minimum flow [m3/h]	1.21
Minimum ffrequency [1/min]	1584

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.1361
f	-0.0072

Modes

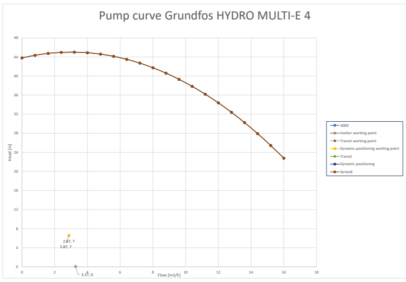
Harbor	
Flow [m3/h]	3.27
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	37%
Power consumption [Kw]	1.21

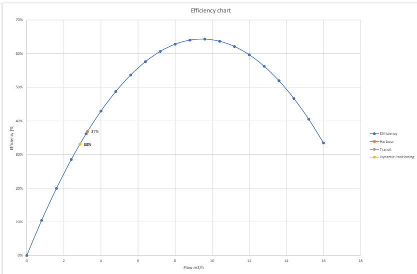
Transit	
Flow [m3/h]	2.87
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	33%
Power consumption [Kw]	1.18

Dynamic positioning	
Flow [m3/h]	2.87
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	33%
Power consumption [Kw]	1.18

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	34
b	0.2474
c	-0.0115

Efficiancy motor [1]	0.9
Frequenzy [1/min]	2640
Max flow at given frequenzy [m3/h]	41
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0478
f	-0.0008

Modes

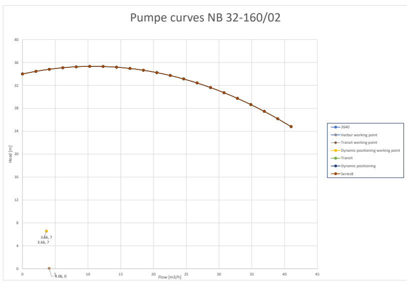
Harbor	
Flow [m3/h]	4.06
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.36

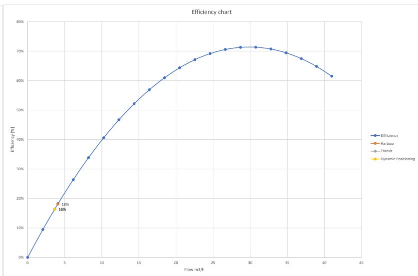
Transit	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	16%
Power consumption [Kw]	2.34

Dynamic positioning	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	16%
Power consumption [Kw]	2.34

Fit curves to working points

Reset frequency





Summary of the pump calculations middle weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	6.06
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	15%
Power consumption [Kw]	4.00
0	0
Transit	
Flow [m3/h]	5.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	14%
Power consumption [Kw]	3.98
0	0
Dynamic positioning	
Flow [m3/h]	5.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	14%
Power consumption [Kw]	3.98

NB 32 125/01

Harbor	
Flow [m3/h]	4.06
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	20%
Power consumption [Kw]	2.09
0	0
Transit	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07
0	0
Dynamic positioning	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.07

NB 32-160/02

Harbor	
Flow [m3/h]	4.06
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	18%
Power consumption [Kw]	2.36
0	0
Transit	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	16%
Power consumption [Kw]	2.34
0	0
Dynamic positioning	
Flow [m3/h]	3.66
Head required [m]	7
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	16%
Power consumption [Kw]	2.34

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Harbor	
Flow [m3/h]	3.27
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	37%
Power consumption [Kw]	1.21
0	0
Transit	
Flow [m3/h]	2.87
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	33%
Power consumption [Kw]	1.18
0	0
Dynamic positioning	
Flow [m3/h]	2.87
Head required [m]	7
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	33%
Power consumption [Kw]	1.18

Constant flow system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.21
Power saving[Kw]	3.19
Power saving potential [%]	73%
Power consumption scaling factor [1]	0.27
Transit	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.18
Power saving[Kw]	3.22
Power saving potential [%]	73%
Power consumption scaling factor [1]	0.27
Dynamic positioning	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.18
Power saving[Kw]	3.22
Power saving potential [%]	73%
Power consumption scaling factor [1]	0.27

Fuel consumption

Harbor		
Annual energy demand Constant flow [kWh]		1 387
Annual energy demand dynamic [kWh]		381
Fuel consumption Constant flow [kg]		298.9
Fuel consumption dynamic [kg]		82.1
Annual fuel cost Constant flow system	NOK	5 380
Annual fuel cost dynamic system	NOK	1 478
Annual savings	NOK	3 902
Transit		
Annual energy demand Constant flow [kWh]		324
Annual energy demand dynamic [kWh]		87
Fuel consumption Constant flow [kg]		65.6
Fuel consumption dynamic [kg]		17.6
Annual fuel cost Constant flow system	NOK	1 181
Annual fuel cost dynamic system	NOK	316
Annual savings	NOK	865
Dynamic positioning		
Annual energy demand Constant flow [kWh]		7 536
Annual energy demand dynamic [kWh]		2 018
Fuel consumption Constant flow [kg]		1531.6
Fuel consumption dynamic [kg]		410.2
Annual fuel cost Constant flow system	NOK	27 569
Annual fuel cost dynamic system	NOK	7 384
Annual savings	NOK	20 185

Average daily savings	NOK	285
Total annual savings	NOK	24 952
Total annual fuel saving [kg]		1386.2

Potential savings in emissions

Annual Co2 emissions [kg]	4044.92
Annual Nox emissions [kg]	41.10
Annual Co emissions [kg]	2.20
Annual HC emissions [kg]	1.28
Annual part matter emissions [kg]	0.33

This is the potential for savings by swiching from a static flow system without throtteling to a dynamic flow system, either with frequency controllig or using just throttleing depending on the pump curves were fit the the working points or kept at a constant frequency.

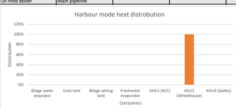
A.10 Power Consumption During Warm Conditions

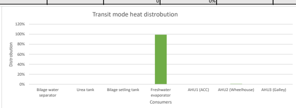
Central heating Balance Warm weather

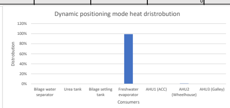
Consumers:	Location:	Max Load [kW]:	Maximum flow [m3/h]	Harbor: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	Branch 1	160	5.5	No	100%	0	0%	-	-
Urea tank	Branch 2	25	1.8	No	100%	0	0%	-	-
Bilage setling tank	Branch 3	18	1.5	No	100%	0	0%	-	-
Freshwater evaporator	Branch 4	742.8	66.2	No	100%	0	0%	-	-
AHU1 (ACC)	Main pipeline	489.5	21.5	Yes	0.0%	0	0%	-	21.50
AHU2 (Wheelhouse)	Branch 5	44	1.94	Yes	14.0%	6.16	100%	0.27	1.94
AHU3 (Galley)	Branch 6	90	3.96	Yes	0.0%	0	0%	-	3.96
Example consumer		0	0		100.0%	0	0%	-	-
							Flow through central heating pump [m3/h]	0.3	27.4
							Flow through FW	-	-
Heat providers and loss:									
Heatloss	Entire system	5			100%	5	1%		
Heat recovery units	Main pipeline	2368		-	21%	497.28	99%		
Oil fired boiler	Main pipeline					0	0%		

Consumers:	Transit: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	No	100%	0	0%	-	-
Urea tank	No	100%	0	0%	-	-
Bilage setling tank	No	100%	0	0%	-	-
Freshwater evaporator	Yes	100%	742.8	99%	66.20	66.20
AHU1 (ACC)	Yes	0.0%	0	0%	-	21.50
AHU2 (Wheelhouse)	Yes	15.0%	6.6	1%	0.29	1.94
AHU3 (Galley)	Yes	0.0%	0	0%	-	3.96
Example consumer		100.0%	0	0%	-	-
				Flow through central heating pump [m3/h]	0.3	27.4
				Flow through FW	66.20	66.20
Heat providers and loss:						
Heatloss		100%	5	0%		
Heat recovery units	-	73%	1731.008	100%		
Oil fired boiler			0	0%		

Consumers:	Dynamic positioning: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	No	100%	0	0%	-	-
Urea tank	No	100%	0	0%	-	-
Bilage setling tank	No	100%	0	0%	-	-
Freshwater evaporator	Yes	100%	742.8	99%	66.20	66.20
AHU1 (ACC)	Yes	0.0%	0	0%	-	21.50
AHU2 (Wheelhouse)	Yes	15.0%	6.6	1%	0.29	1.94
AHU3 (Galley)	Yes	0.0%	0	0%	-	3.96
Example consumer		100.0%	0	0%	-	-
				Flow through central heating pump [m3/h]	0.3	27.4
				Flow through FW	66.20	66.20
Heat providers and loss:						
Heatloss		100%	5	0%		
Heat recovery units	-	78%	1837.568	100%		
Oil fired boiler			0	0%		







Consumption data		
Distrobution of year spent in these conditions [%]		39%
Average fuel price [kr/g]	NOK	0.018
Harbor		
Fuel consumption per [g/Kwh]		215.50
Distrobution spent in mode [%]		15%
Transit		
Fuel consumption per [g/Kwh]		202.80
Distrobution spent in mode [%]		3.5%
Dynamic positioning		
Fuel consumption per [g/Kwh]		203.25
Distrobution spent in mode [%]		81.5%

Fuel emission data	
Greenhouse gass	g/kg fuel
Co2	2918
Nox	29.65
Co	1.59
HC	0.92
Part matter	0.24

Pressure drop through main pipeline [m water colum]	0.000	15.190
Flow through central heating pump	0.2716	27.4

	Kv value [m3/h/bar]	Harbor: Flow [m3/h]	Harbor: Flow Constant flow system [m	Harbor: Pressure drop in section [Bar]	Harbor: Pressure drop Constant flow system [bar]
Section 0	639.52	0.27	27.40	0.000	0.002
Section 1	342.39	0.27	27.40	0.000	0.006
Section 2	337.88	0.27	27.40	0.000	0.007
Section 9	112.99	0.27	27.40	0.000	0.059
Section 10	130.36	0.27	23.44	0.000	0.032
Section 11	20.43	-	21.50	-	1.107
Section 12	130.7	0.27	23.44	0.000	0.032
Section 13	110.45	0.27	27.40	0.000	0.062
Section 3	264.4	0.27	27.40	0.000	0.011
Section 4	113.33	0.27	27.40	0.000	0.058
Section 5	334.79	0.27	27.40	0.000	0.007
Section 6	624.11	0.27	27.40	0.000	0.002
Section 7	168.22	0.27	27.40	0.000	0.027
Section 8	98.24	0.27	27.40	0.000	0.078

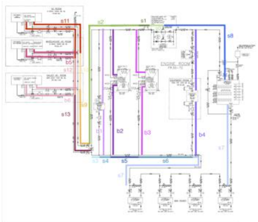
Pressure drop through main pipeline [m water colum]	6.266	26.543
Flow through central heating pump	0.291	27.4

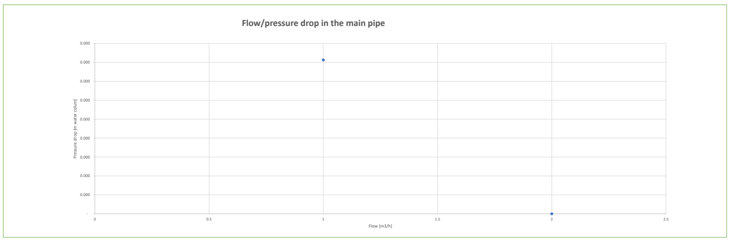
	Transit: Flow [m3/h]	Transit: Flow Constant flow system [m	Transit: Pressure drop in section [Bar]	Transit: Pressure drop Constant flow system [bar]
Section 0	0.29	27.40	0.000	0.002
Section 1	0.29	27.40	0.000	0.006
Section 2	0.29	27.40	0.000	0.007
Section 9	0.29	27.40	0.000	0.059
Section 10	0.29	23.44	0.000	0.032
Section 11	-	21.50	-	1.107
Section 12	0.29	23.44	0.000	0.032
Section 13	0.29	27.40	0.000	0.062
Section 3	0.29	27.40	0.000	0.011
Section 4	0.29	27.40	0.000	0.058
Section 5	0.29	27.40	0.000	0.007
Section 6	0.29	27.40	0.000	0.002
Section 7	66.49	93.60	0.156	0.310
Section 8	66.49	93.60	0.458	0.908

Pressure drop through main pipeline [m water colum]	6.266	26.543
Flow through central heating pump	0.291	27.4

	Dynamic positioning: Flow [m3/h]	Dynamic positioning: Flow Constant flow system [m	Dynamic positioning: Pressure drop in section [Bar]	Dynamic positioning: Pressure drop Constant flow system [bar]
Section 0	0.29	27.40	0.000	0.002
Section 1	0.29	27.40	0.000	0.006
Section 2	0.29	27.40	0.000	0.007
Section 9	0.29	27.40	0.000	0.059
Section 10	0.29	23.44	0.000	0.032
Section 11	-	21.50	-	1.107
Section 12	0.29	23.44	0.000	0.032
Section 13	0.29	27.40	0.000	0.062
Section 3	0.29	27.40	0.000	0.011
Section 4	0.29	27.40	0.000	0.058
Section 5	0.29	27.40	0.000	0.007
Section 6	0.29	27.40	0.000	0.002
Section 7	66.49	93.60	0.156	0.310
Section 8	66.49	93.60	0.458	0.908

This calculates the pressure drop through the main pipe in each Mode. This is done by considering the pressure drop during full operation and assigning a Kv value to each branch. This is done with an assumption that the pressure drop in each section is proportional to the square of the flow. This is true as long as there are no dynamic valves restricting the flow, which is only in section 11. This flow is always constant regardless of the other brances, so the assumption is true.





Pump curve polynomial

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

a	45
b	0.175
c	-0.015

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3600
Max flow at given frequenzy [m3/h]	48
Minumum flow [m3/h]	16
Mimimum frequency [1/min]	3513

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0441
f	-0.0007

Modes

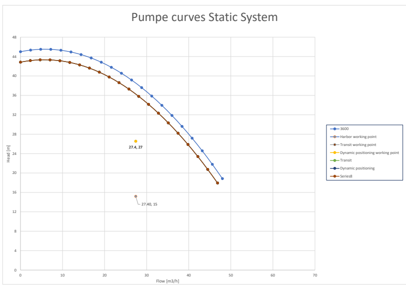
Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

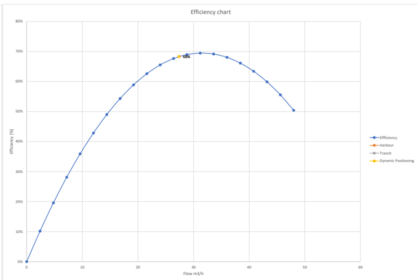
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	33.5
b	0.01675
c	-0.00317

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	68
Minimum flow [m3/h]	4
Mimimum frequency [1/min]	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0271
f	-0.0003

Modes

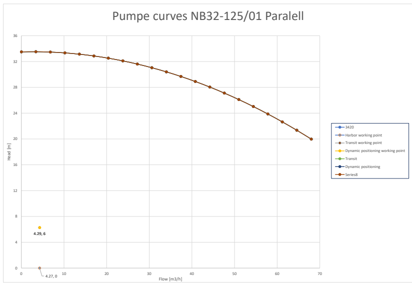
Harbor	
Flow [m3/h]	4.27
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92

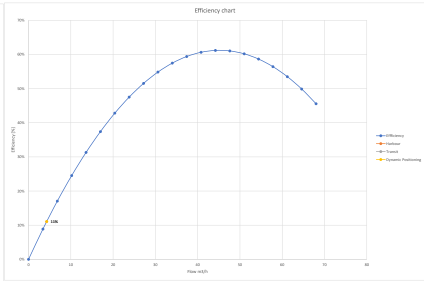
Transit	
Flow [m3/h]	4.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92

Dynamic positioning	
Flow [m3/h]	4.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	33.5
b	0.118
c	-0.0174

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3420
Max flow at given frequenzy [m3/h]	32
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0535
f	-0.0012

Modes

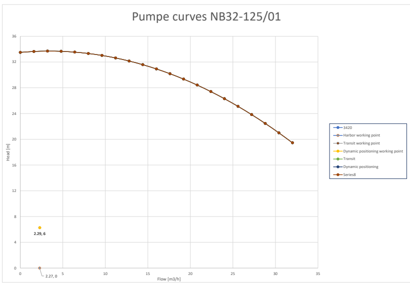
Harbor	
Flow [m3/h]	2.27
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.00

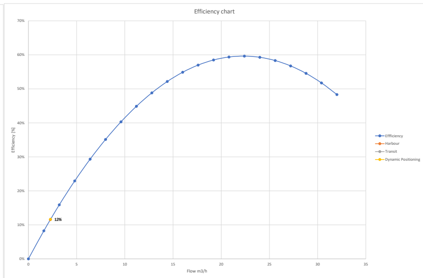
Transit	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.01

Dynamic positioning	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.01

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	34
b	0.2474
c	-0.0115

Efficiancy motor [1]	0.9
Frequenzy [1/min]	2640
Max flow at given frequenzy [m3/h]	41
Minimum flow [m3/h]	2
Minimum frequency	1800

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0478
f	-0.0008

Modes

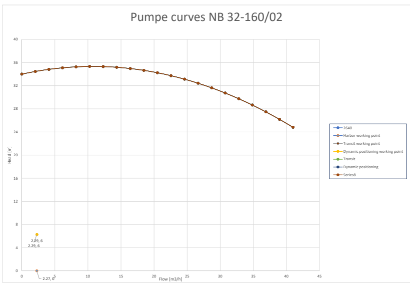
Harbor	
Flow [m3/h]	2.27
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	2.27

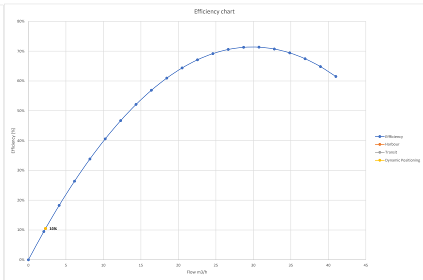
Transit	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	2.27

Dynamic positioning	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	2.27

Fit curves to working points

Reset frequency





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	43.8
b	0.8
c	-0.1321

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3000
Max flow at given frequenzy [m3/h]	16
Minimum flow [m3/h]	1.21
Minimum ffrequency [1/min]	1584

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.1361
f	-0.0072

Modes

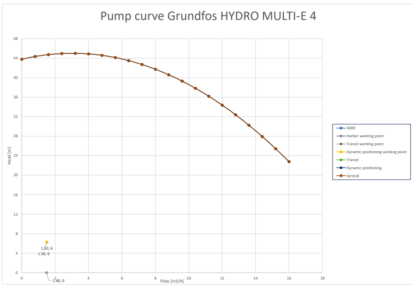
Harbor	
Flow [m3/h]	1.48
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08

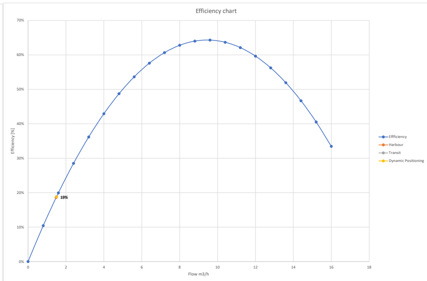
Transit	
Flow [m3/h]	1.50
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08

Dynamic positioning	
Flow [m3/h]	1.50
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08

Fit curves to working points

Reset frequency





Summary of the pump calculations warm weather

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	4.27
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92
0	0
Transit	
Flow [m3/h]	4.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92
0	0
Dynamic positioning	
Flow [m3/h]	4.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	3.92

NB 32 125/01

Harbor	
Flow [m3/h]	2.27
Head required [m]	0
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.00
0	0
Transit	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.01
0	0
Dynamic positioning	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	12%
Power consumption [Kw]	2.01

NB 32-160/02

Harbor	
Flow [m3/h]	2.27
Head required [m]	0
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	10%
Power consumption [Kw]	2.27
0	0
Transit	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	2.27
0	0
Dynamic positioning	
Flow [m3/h]	2.29
Head required [m]	6
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	11%
Power consumption [Kw]	2.27

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Harbor	
Flow [m3/h]	1.48
Head required [m]	0
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08
0	0
Transit	
Flow [m3/h]	1.50
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08
0	0
Dynamic positioning	
Flow [m3/h]	1.50
Head required [m]	6
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	19%
Power consumption [Kw]	1.08

Constant flow system

Harbor	
Flow [m3/h]	27.40
Head [m]	15
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Transit	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40
0	0
Dynamic positioning	
Flow [m3/h]	27.4
Head [m]	27
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.40

Pump power consumption saving

Harbor	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.08
Power saving[Kw]	3.32
Power saving potential [%]	76%
Power consumption scaling factor [1]	0.24
Transit	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.08
Power saving[Kw]	3.32
Power saving potential [%]	75%
Power consumption scaling factor [1]	0.25
Dynamic positioning	
Power consumption with Constant flow system [Kw]	4.40
Power consumption with dynamic system [Kw]	1.08
Power saving[Kw]	3.32
Power saving potential [%]	75%
Power consumption scaling factor [1]	0.25

Fuel consumption

Harbor		
Annual energy demand Constant flow [kWh]		2 254
Annual energy demand dynamic [kWh]		552
Fuel consumption Constant flow [kg]		485.7
Fuel consumption dynamic [kg]		118.9
Annual fuel cost Constant flow system	NOK	8 742
Annual fuel cost dynamic system	NOK	2 140
Annual savings	NOK	6 602
Transit		
Annual energy demand Constant flow [kWh]		526
Annual energy demand dynamic [kWh]		129
Fuel consumption Constant flow [kg]		106.6
Fuel consumption dynamic [kg]		26.1
Annual fuel cost Constant flow system	NOK	1 920
Annual fuel cost dynamic system	NOK	471
Annual savings	NOK	1 449
Dynamic positioning		
Annual energy demand Constant flow [kWh]		12 245
Annual energy demand dynamic [kWh]		3 002
Fuel consumption Constant flow [kg]		2488.9
Fuel consumption dynamic [kg]		610.1
Annual fuel cost Constant flow system	NOK	44 799
Annual fuel cost dynamic system	NOK	10 982
Annual savings	NOK	33 817

Average daily savings	NOK	294
Total annual savings	NOK	41 868
Total annual fuel saving [kg]		2326.0

Potential savings in emissions

Annual Co2 emissions [kg]	6787.25
Annual Nox emissions [kg]	68.97
Annual Co emissions [kg]	3.70
Annual HC emissions [kg]	2.14
Annual part matter emissions [kg]	0.56

This is the potential for savings by swiching from a static flow system without throtteling to a dynamic flow system, either with frequency controllig or using just throttleing depending on the pump curves were fit the the working points or kept at a constant frequency.

A.11 Power Consumption Summary

Summary of potential annual savings from all weather conditions	Cold conditions	Middle conditions	Warm conditions	Total annual savings
Total annual savings	**NOK 35 799**	**NOK 24 952**	**NOK 41 868**	**NOK 102 619**
Total annual fuel saving [kg]	1989	1386	2326	**5 701**
Emissions				
Annual Co2 emissions [kg]	5803	4045	6787	16636
Annual Nox emissions [kg]	59.0	41.1	69.0	169.0
Annual Co emissions [kg]	3.2	2.2	3.7	9.1
Annual HC emissions [kg]	1.8	1.3	2.1	5.2
Annual part matter emissions [kg]	0.5	0.3	0.6	1.4
Power scaling factor				
Harbor	0.33	0.27	0.24	0.28
Potential power saving [%]	0.67	0.73	0.76	72%
Distrobution throughout year	5.6%	3.6%	5.9%	15.0%
Transit	0.32	0.27	0.25	0.28
Potential power saving [%]	68%	73%	75%	72%
Distrobution throughout year	1%	1%	1%	3.5%
Dynamic positioning	0.32	0.27	0.25	0.28
Potential power saving [%]	68%	73%	75%	72%
Distrobution throughout year [%]	30%	20%	32%	82%
			Total Power saving factor	0.28
	Yearly distrobution check:	100%	Total power saving [%]	72%

A.12 Power Consumption During Worst Case Scenario

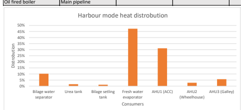
Central heating Balance worst case

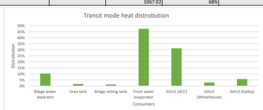
Consumers:	Location:	Max Load [kW]:	Maximum flow [m3/h]
Bilage water separator	Branch 1	160	5.5
Urea tank	Branch 2	25	1.8
Bilage setling tank	Branch 3	18	1.5
Fresh water evaporator	Branch 4	742.8	66.2
AHU1 (ACC)	Main pipeline	489.5	21.5
AHU2 (Wheelhouse)	Branch 5	44	1.94
AHU3 (Galley)	Branch 6	90	3.96
Example consumer		0	0
Heat providers and loss:			
Heatloss	Entire system	5	
Heat recovery units	Main pipeline	2368	
Oil fired boiler	Main pipeline		

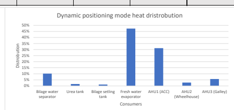
Consumers:	Harbor: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	Yes	100%	160	10%	5.50	5.50
Urea tank	Yes	100%	25	2%	1.80	1.80
Bilage setling tank	Yes	100%	18	1%	1.50	1.50
Fresh water evaporator	Yes	100%	742.8	47%	66.20	66.20
AHU1 (ACC)	Yes	100%	489.5	31%	21.50	21.50
AHU2 (Wheelhouse)	Yes	100%	44	3%	1.94	1.94
AHU3 (Galley)	Yes	100%	90	6%	3.96	3.96
Example consumer		100%	0	0%	-	-
				Flow through central heating pump [m3/h]	36.2	36.2
				Flow through FW	66.20	66.20
Heatloss		100%	5	0%		
Heat recovery units	-	21%	497.28	32%		
Oil fired boiler			1067.02	68%		

Consumers:	Transit: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	Yes	100%	160	10%	5.50	5.50
Urea tank	Yes	100%	25	2%	1.80	1.80
Bilage setling tank	Yes	100%	18	1%	1.50	1.50
Fresh water evaporator	Yes	100%	742.8	47%	66.20	66.20
AHU1 (ACC)	Yes	100%	489.5	31%	21.50	21.50
AHU2 (Wheelhouse)	Yes	100%	44	3%	1.94	1.94
AHU3 (Galley)	Yes	100%	90	6%	3.96	3.96
Example consumer		100%	0	0%	-	-
				Flow through central heating pump [m3/h]	36.2	36.2
				Flow through FW	66.20	66.20
Heatloss		100%	5	0%		
Heat recovery units	-	82%	1941.76	100%		
Oil fired boiler			0	0%		

Consumers:	Dynamic positioning: Active	Capacity [%]	Load [Kw]	Heat distrobution [%]	Flow m3/h	Constant flow flow m3/h
Bilage water separator	Yes	100%	160	10%	5.50	5.50
Urea tank	Yes	100%	25	2%	1.80	1.80
Bilage setling tank	Yes	100%	18	1%	1.50	1.50
Fresh water evaporator	Yes	100%	742.8	47%	66.20	66.20
AHU1 (ACC)	Yes	100%	489.5	31%	21.50	21.50
AHU2 (Wheelhouse)	Yes	100%	44	3%	1.94	1.94
AHU3 (Galley)	Yes	100%	90	6%	3.96	3.96
Example consumer		100%	0	0%	-	-
				Flow through central heating pump [m3/h]	36.2	36.2
				Flow through FW	66.20	66.20
Heatloss		100%	5	0%		
Heat recovery units	-	82%	1941.76	100%		
Oil fired boiler			0	0%		







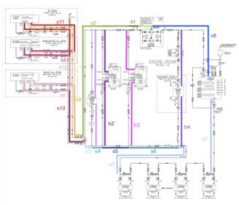
Consumption data		
Distrobution of year spent in these conditions [%]		37%
Average fuel price [kr/g]	NOK	0.018
Harbor		
Fuel consumption per [g/Kwh]		215.50
Distrobution spent in mode [%]		15%
Transit		
Fuel consumption per [g/Kwh]		202.80
Distrobution spent in mode [%]		3.5%
Dynamic positioning		
Fuel consumption per [g/Kwh]		203.25
Distrobution spent in mode [%]		81.5%

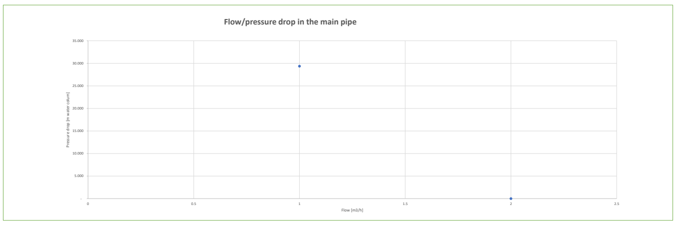
Fuel emission data	
Greenhouse gass	g/kg fuel
Co2	2918
Nox	29.65
Co	1.59
HC	0.92
Part matter	0.24

	Harbor			Transit			Dynamic positioning		
Pressure drop through main pipeline [m water colum]	29.370	29.370		29.370	29.370		29.370	29.370	
Flow through central heating pump	36.2	36.2		36.2	36.2		36.2	36.2	

	Kv value [m3/h/bar]	Harbor: Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]	Transit: Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]	Dynamic positioning: Flow [m3/h]	Flow Constant flow system [m3/h]	Pressure drop in section [Bar]	Pressure drop Constant flow system [bar]
Section 0	639.52	36.20	36.20	0.003	0.003	36.20	36.20	0.003	0.003	36.20	36.20	0.003	0.003
Section 1	342.39	36.20	36.20	0.011	0.011	36.20	36.20	0.011	0.011	36.20	36.20	0.011	0.011
Section 2	337.88	27.40	27.40	0.007	0.007	27.40	27.40	0.007	0.007	27.40	27.40	0.007	0.007
Section 9	112.99	27.40	27.40	0.059	0.059	27.40	27.40	0.059	0.059	27.40	27.40	0.059	0.059
Section 10	130.36	23.44	23.44	0.032	0.032	23.44	23.44	0.032	0.032	23.44	23.44	0.032	0.032
Section 11	20.43	21.50	21.50	1.107	1.107	21.50	21.50	1.107	1.107	21.50	21.50	1.107	1.107
Section 12	130.7	23.44	23.44	0.032	0.032	23.44	23.44	0.032	0.032	23.44	23.44	0.032	0.032
Section 13	110.45	27.40	27.40	0.062	0.062	27.40	27.40	0.062	0.062	27.40	27.40	0.062	0.062
Section 3	264.4	27.40	27.40	0.011	0.011	27.40	27.40	0.011	0.011	27.40	27.40	0.011	0.011
Section 4	113.33	32.90	32.90	0.084	0.084	32.90	32.90	0.084	0.084	32.90	32.90	0.084	0.084
Section 5	334.79	34.70	34.70	0.011	0.011	34.70	34.70	0.011	0.011	34.70	34.70	0.011	0.011
Section 6	624.11	36.20	36.20	0.003	0.003	36.20	36.20	0.003	0.003	36.20	36.20	0.003	0.003
Section 7	168.22	102.40	102.40	0.371	0.371	102.40	102.40	0.371	0.371	102.40	102.40	0.371	0.371
Section 8	98.24	102.40	102.40	1.086	1.086	102.40	102.40	1.086	1.086	102.40	102.40	1.086	1.086

This calculates the pressure drop through the main pipe in each Mode. This is done by considering the pressure drop during full operation and assigning a Kv value to each branch. This is done with an assumption that the pressure drop in each section is proportional to the square of the flow. This is true as long as there are no dynamic valves restricting the flow, which is only in section 11. This flow is always constant regardless of the other brances, so the assumption is true.





Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	45
b	0.175
c	-0.015

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3600
Max flow at given frequenzy [m3/h]	48
Minumum flow [m3/h]	16
Mimimum frequency [1/min]	3513

Modes

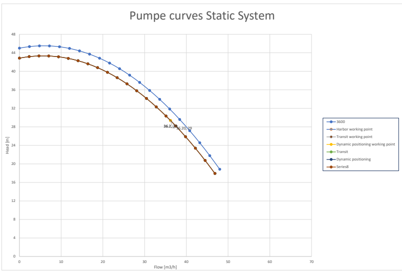
Harbor	
Flow [m3/h]	36.20
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73

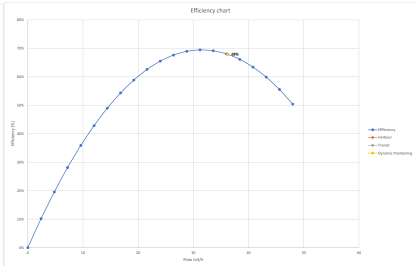
Transit	
Flow [m3/h]	36.2
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73

Dynamic positioning	
Flow [m3/h]	36.2
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73

Fit curves to working points

Reset frequency





Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0441
f	-0.0007

Pump curve polynomial

$$H(Q) = a + b \cdot Q + c \cdot Q^2$$

Estimate a curve for the pump at a constant frequency using curve fitting software. With Q values in m3/h and H in m.

a	44.59
b	0.1256
c	-0.0116

Efficiancy motor [1]	0.9
Frequenzy [1/min]	3000
Max flow at given frequenzy [m3/h]	48
Minimum flow [m3/h]	4.84
Minimum ffrequency [1/min]	1584

Efficiency polynomial

$$\eta(Q) = d + e \cdot Q + f \cdot Q^2$$

d	0
e	0.0376
f	-0.00054

Modes

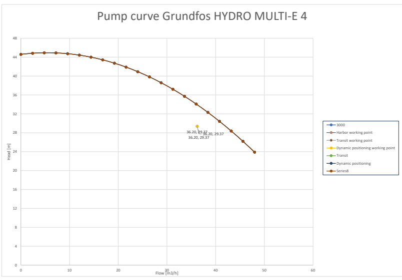
Harbor	
Flow [m3/h]	36.20
Head required [m]	29.37
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68

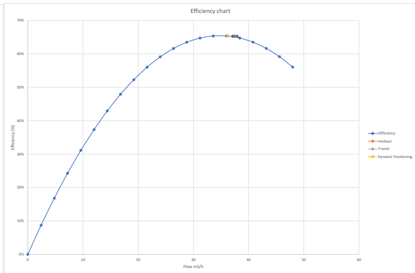
Transit	
Flow [m3/h]	36.20
Head required [m]	29.37
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68

Dynamic positioning	
Flow [m3/h]	36.20
Head required [m]	29.37
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68

Fit curves to working points

Reset frequency





Summary of the pump calculations worst case

Dynamic system

NB 32 125/01 Parallel

Harbor	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	59%
Power consumption [Kw]	0.00
0	0
Transit	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	59%
Power consumption [Kw]	0.00
0	0
Dynamic positioning	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	59%
Power consumption [Kw]	0.00

NB 32 125/01

Harbor	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	36%
Power consumption [Kw]	0.00
0	0
Transit	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	36%
Power consumption [Kw]	0.00
0	0
Dynamic positioning	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3420
Change of frequenzy C	100%
Efficiency [%]	36%
Power consumption [Kw]	0.00

NB 32-160/02

Harbor	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	68%
Power consumption [Kw]	0.00
0	0
Transit	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	68%
Power consumption [Kw]	0.00
0	0
Dynamic positioning	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	2640
Change of frequenzy C	100%
Efficiency [%]	68%
Power consumption [Kw]	0.00

Grundfos HYDRO MULTI-E 4

Harbor	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68
0	0
Transit	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68
0	0
Dynamic positioning	
Flow [m3/h]	36.20
Head required [m]	29
Frequenzy [1/min]	3000
Change of frequenzy C	100%
Efficiency [%]	65%
Power consumption [Kw]	5.68

Constant flow system

Harbor	
Flow [m3/h]	36.20
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73
0	0
Transit	
Flow [m3/h]	36.2
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73
0	0
Dynamic positioning	
Flow [m3/h]	36.2
Head [m]	29
Frequenzy [1/min]	3513
Change of frequenzy C	98%
Efficiency [%]	68%
Power consumption [Kw]	4.73

Pump power consumption saving

Harbor	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20
Transit	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20
Dynamic positioning	
Power consumption with static system [Kw]	4.73
Power consumption with dynamic system [Kw]	5.68
Power saving[Kw]	-0.95
Power saving potential [%]	-20%
Power consumption scaling factor [1]	1.20

Fuel consumption

Harbor		
Annual energy demand static [kWh]		2 300
Annual energy demand dynamic [kWh]		2 762
Fuel consumption static [kg]		495.8
Fuel consumption dynamic [kg]		595.2
Annual fuel cost static system	NOK	8 924
Annual fuel cost dynamic system	NOK	10 713
Annual savings	NOK	(1 789)
Transit		
Annual energy demand static [kWh]		537
Annual energy demand dynamic [kWh]		644
Fuel consumption static [kg]		108.9
Fuel consumption dynamic [kg]		130.7
Annual fuel cost static system	NOK	1 959
Annual fuel cost dynamic system	NOK	2 352
Annual savings	NOK	(393)
Dynamic positioning		
Annual energy demand static [kWh]		12 499
Annual energy demand dynamic [kWh]		15 005
Fuel consumption static [kg]		2540.5
Fuel consumption dynamic [kg]		3049.9
Annual fuel cost static system	NOK	45 729
Annual fuel cost dynamic system	NOK	54 897
Annual savings	NOK	(9 169)

Average daily savings	NOK	(84)
Total annual savings	NOK	(11 351)
Total annual fuel saving [kg]		-630.6

This is the potential for savings by swiching from a static flow system without throtteling to a dynamic flow system, either with frequency controllig or using just throttleing depending on the pump curves were fit the the working points or kept at a constant frequency.

Potential savings in emissions

Annual Co2 emissions [kg]	-1840.06
Annual Nox emissions [kg]	-18.70
Annual Co emissions [kg]	-1.00
Annual HC emissions [kg]	-0.58
Annual part matter emissions [kg]	-0.15

A.13 Weather Data at Grimsby

In [22]:

```
#Beregning av i harbor 2020-2021


import pandas as pd
import numpy as np
import csv
import matplotlib.pyplot as plt
```

In [23]:

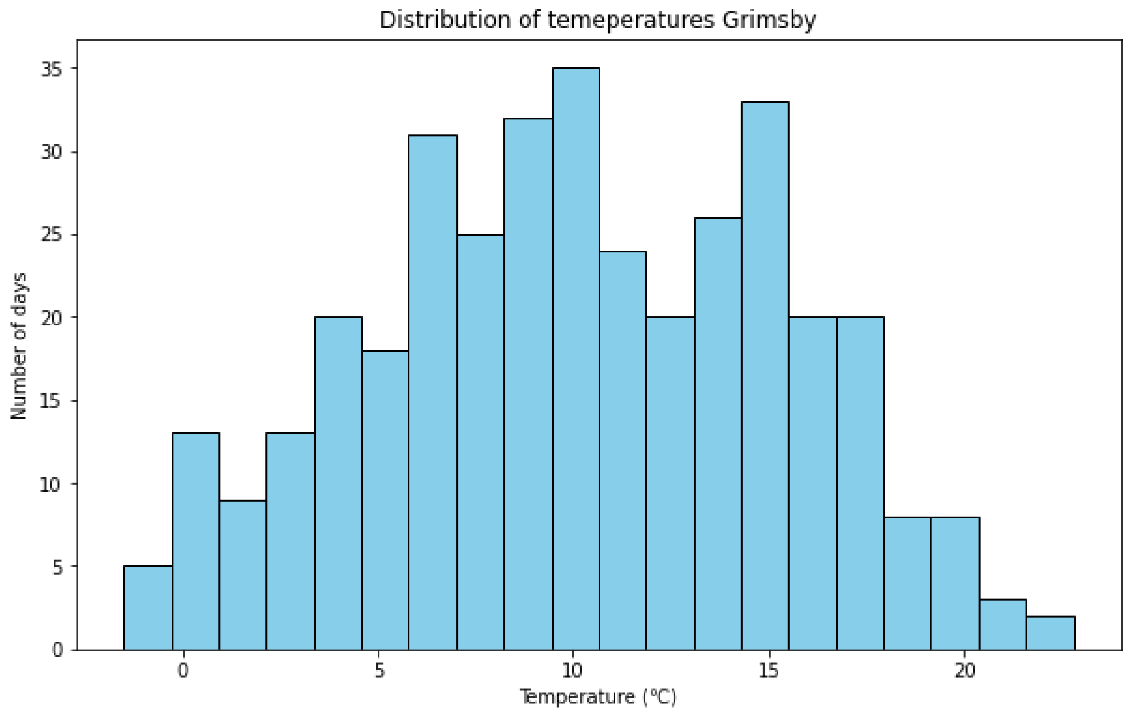
```
spreadsheet = pd.read_csv(r"\Users\sindr\Downloads\grimsby 2020-03-25 to 2021-03-24.csv"
```

In [26]:

```
file_name = r'C:\Users\sindr\Downloads\grimsby 2020-03-25 to 2021-03-24.csv'


temp_values = []

with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)
    for row in csv_reader:
        temp_values.append(float(row['temp']))


total_humidity = 0
num_rows = 0

with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)
    for row in csv_reader:
        # Adds the humidities to a list to find the average
        total_humidity += float(row['humidity'])

        # Row count
        num_rows += 1


average_humidity = total_humidity / num_rows


# Converts the column to a np.array
temp_array = np.array(temp_values)

# Upper and lower quartile and the average
lower_quartile = np.percentile(temp_array, 25)
upper_quartile = np.percentile(temp_array, 75)
average= np.percentile(temp_array, 50)

# Printing the results
print(f'Lower quartile (Q1): {lower_quartile}')
print(f'Upper quartile (Q3): {upper_quartile}')
print(f'Average temeprature {average}')
print(f'The average humidity is: {average_humidity}')


count_above_1225 = 0
count_below_885=0
num_rows=0


with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)

    for row in csv_reader:
        # Check if the 'temp' value is above 12.25
        if float(row['temp']) > 12.25:
            # Counting the number of days
            count_above_1225 += 1
        # Check if the 'temp' value is above 12.25
        if float(row['temp']) < 8.85:
            # Counting the number of days
            count_below_885 += 1
```

```
        # Counting the total number of rows
        num_rows += 1

count_middle=num_rows-count_above_1225-count_below_885

# Printing the results
print(f'The number of warm days is: {count_above_1225}')
print(f'The number of cold days is: {count_below_885}')
print(f'The number of days in with middle temeprature: {count_middle}')

temp_column = spreadsheet['temp']

#Creating a plot of the temperatures
plt.figure(figsize=(10, 6))  #Size of figure
plt.hist(temp_column, bins=20, color='skyblue', edgecolor='black')
plt.xlabel('Temperature (℃)')
plt.ylabel('Number of days')
plt.title('Distribution of temeperatures Grimsby')
plt.show()  # Display the chart
```

```
Lower quartile (Q1): 6.4
Upper quartile (Q3): 14.4
Average temeprature 10.0
The average humidity is: 81.30082191780815
The number of warm days is: 135
The number of cold days is: 148
The number of days in with middle temeprature: 82
```



In [ ]:

A.14 Weather Data at Hornsea

In [9]:

```
#Weather data at the North Sea outside of Grimsby 2020-2021


import pandas as pd
import numpy as np
import csv
import matplotlib.pyplot as plt
```

In [10]:

```
spreadsheet = pd.read_csv(r"\Users\sindr\Downloads\53.928223 0.571587 2020-03-25 to 2021
```

In [ ]:

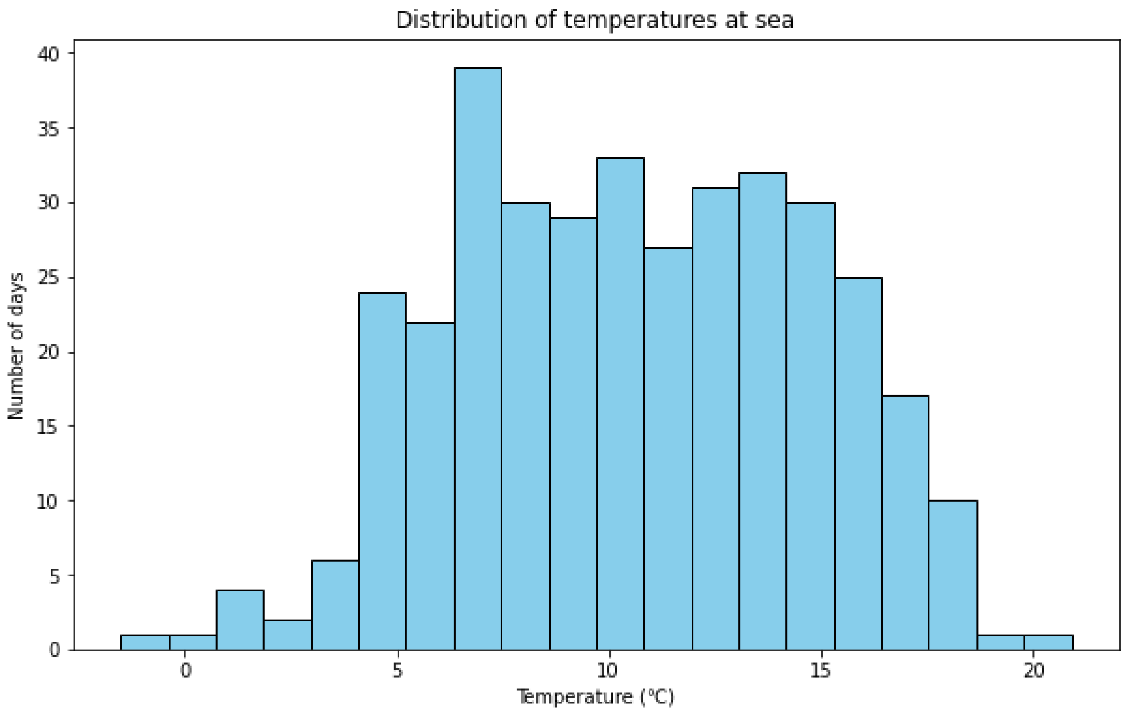
```
```

In [11]:

```
file_name = r'C:\Users\sindr\Downloads\53.928223 0.571587 2020-03-25 to 2021-03-24.csv'


temp_values = []

with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)

    for row in csv_reader:
        # Adds the values in temp to a list
        temp_values.append(float(row['temp']))


total_humidity = 0
num_rows = 0

with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)

    # Calculates the average humidity
    for row in csv_reader:
        total_humidity += float(row['humidity'])

        # Total number of elements
        num_rows += 1

# Calculate the average humidity
average_humidity = total_humidity / num_rows


# Convert the temp column to a numpy array
temp_array = np.array(temp_values)

# Calculating the upper and lower quartile
lower_quartile = np.percentile(temp_array, 25)
upper_quartile = np.percentile(temp_array, 75)
average= np.percentile(temp_array, 50)

# Printing the results
print(f'Lower quartile (Q1): {lower_quartile}')
print(f'Upper quartile (Q3): {upper_quartile}')
print(f'Average temeprature {average}')
print(f'The average humidity is: {average_humidity}')


count_above_1225 = 0
count_below_885=0
num_rows=0

with open(file_name, 'r') as csv_file:
    csv_reader = csv.DictReader(csv_file)

    for row in csv_reader:
        # Check if the 'temp' value is above 12.25
        if float(row['temp']) > 12.25:
            # Counts the number of elements
            count_above_1225 += 1
        # Check if the 'temp' value is above 12.25
        if float(row['temp']) < 8.85:
```

```
            # Counts the number of elements
            count_below_885 += 1

        # Total number of elements
        num_rows += 1

count_middle=num_rows-count_above_1225-count_below_885

# Print the result
print(f'The number of warm days is: {count_above_1225}')
print(f'The number of cold days is: {count_below_885}')
print(f'The number of days in with middle temeprature: {count_middle}')


temp_column = spreadsheet['temp']

#Creating a plot of the temperatures
plt.figure(figsize=(10, 6))  #Size of figure
plt.hist(temp_column, bins=20, color='skyblue', edgecolor='black')
plt.xlabel('Temperature (℃)')
plt.ylabel('Number of days')
plt.title('Distribution of temperatures at sea')
plt.show()  # Display the chart
```

```
Lower quartile (Q1): 7.2
Upper quartile (Q3): 14.0
Average temeprature 10.5
The average humidity is: 80.73863013698632
The number of warm days is: 144
The number of cold days is: 136
The number of days in with middle temeprature: 85
```



In [ ]:

A.15 Data Sheet Grundfos pump

![GRUNDFOS logo]

Company name:	Grundfos
Created by:	
Phone:	
Date:	14/04/2023

Qty.	Description
1	**HYDRO MULTI-E 4 CRIE 10-3**

Note! Product picture may differ from actual product

Product No.: 98486782

GRUNDFOS Hydro Multi-E booster sets are designed for the transfer and pressure boosting of clean water in waterworks, blocks of flats, hotels, industry, hospitals, schools, etc.

GRUNDFOS Hydro Multi-E booster set consists of 2 to 4 CRIE pumps coupled in parallel and mounted on a common base frame provided with all the necessary fittings.

Hydro Multi-E is mounted on a common base frame made of stainless steel (DIN W.-Nr. 1.4301).
On the suction side are fitted a suction manifold (DIN W.-Nr.
1.4401 or DIN W.-Nr.
1.4571) , a pressure switch mounted on a drainable valve and an isolating valve.
On the discharge side of the pumps are fitted a non-return valve, an isolating valve, a pressure gauge, two pressure transmitters mounted on a drainable valve a diaphragm tank and a stainless steel discharge manifold (DIN W.-Nr.

1.4401 or DIN W.-Nr.
1.4571).
The Hydro Multi-E is fitted with an on/off-switch for the supply voltage.

The Hydro Multi-E is designed for maintaining a constant pressure regardless of flow changes and fluctuation.

The internal PI-controller regulates the number of running pumps and the speed of the pumps according to the required flow.

The system can be operated directly on the panel of any of the pumps or via Grundfos GO (available as accessory)

Besides the system features:
2 Digital outputs
2 Digital inputs (one used for dry run protection)
2 Analogue inputs (one used for discharge pressure sensor)
Multi-Master functionality
2 Limit functions
Set-point influence function
Pipe filling function
High efficient PM motors

Available communication protocols:
•LON
•Profibus
•Modbus
•SMS/GSM/GPRS
•GRM
•BACnet
•BACnet IP
•Modbus TCP
•PROFINET

Company name:	Grundfos
Created by:	
Phone:	
Date:	14/04/2023

Qty.	Description
1	When delivered, the GRUNDFOS Hydro Multi-E booster set is factory tested and ready for operation.

Liquid:

Pumped liquid:	Vann
Liquid temperature range:	5 .. 60 °C
Selected liquid temperature:	20 °C
Density:	998.2 kg/m³
Kinematic viscosity:	1 mm2/s

Technical:

Max flow:	62.8 m³/h

Materials:

Pump housing:	Stainless steel

Installation:

Maximum operating pressure:	10 bar
Maximum permissible inlet pressure:	PN 10 bar
Flange standard:	DIN2642
Manifold inlet:	DN 80
Manifold outlet:	DN 80

Electrical data:

IE Efficiency class:	IE5
Power (P2) main pump:	2.2 kW
Mains frequency:	50 / 60 Hz
Rated voltage:	3 x 380-415 V
Rated current:	16.1 A
Start. method:	electronically
Enclosure class (IEC 34-5):	IP54

Tank:

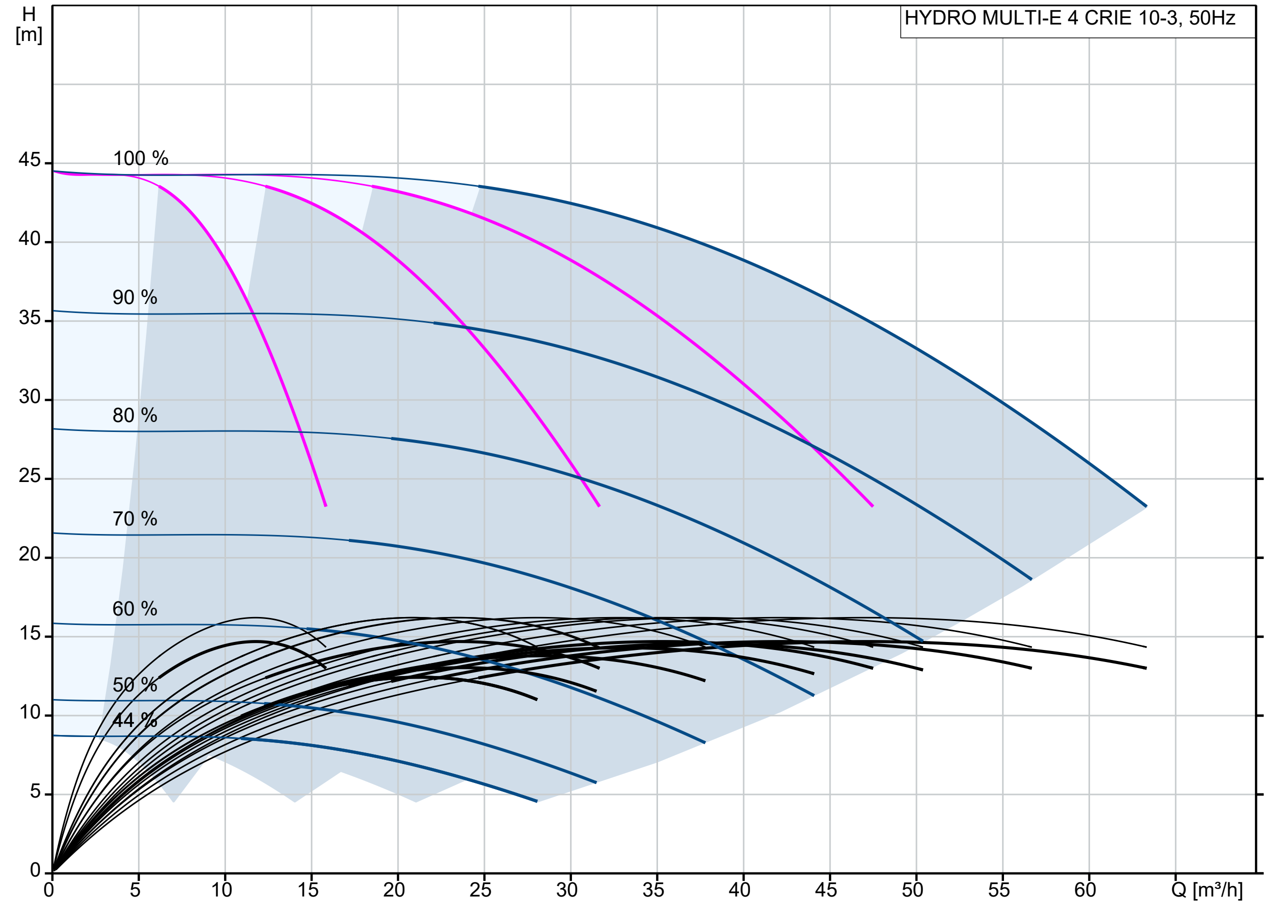
Volume of pressure tank:	8 l
Diaphragm tank:	Yes

Others:

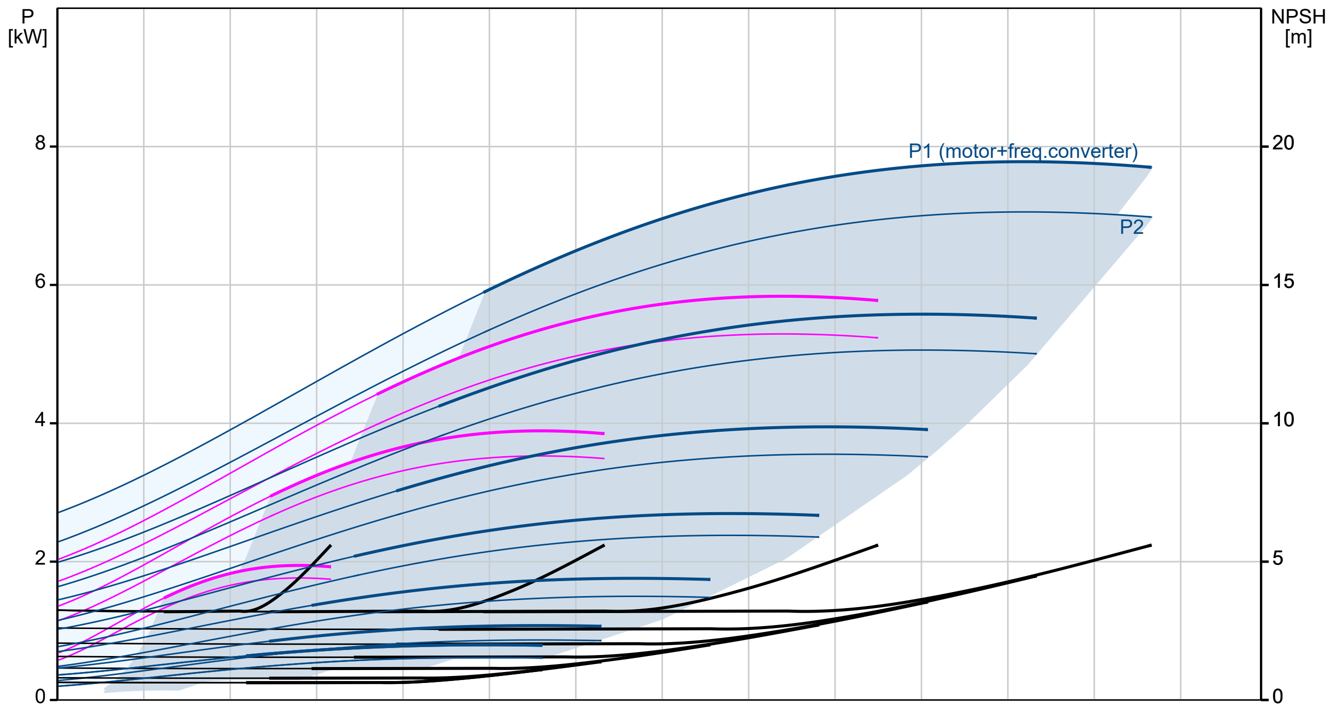
Net weight:	268 kg
Gross weight:	284 kg
Shipping volume:	0.8 m³
Language:	GB
Country of origin:	DE
Custom tariff no.:	84137075

Company name:	Grundfos
Created by:	
Phone:	
Date:	14/04/2023

98486782 HYDRO MULTI-E 4 CRIE 10-3 50 Hz



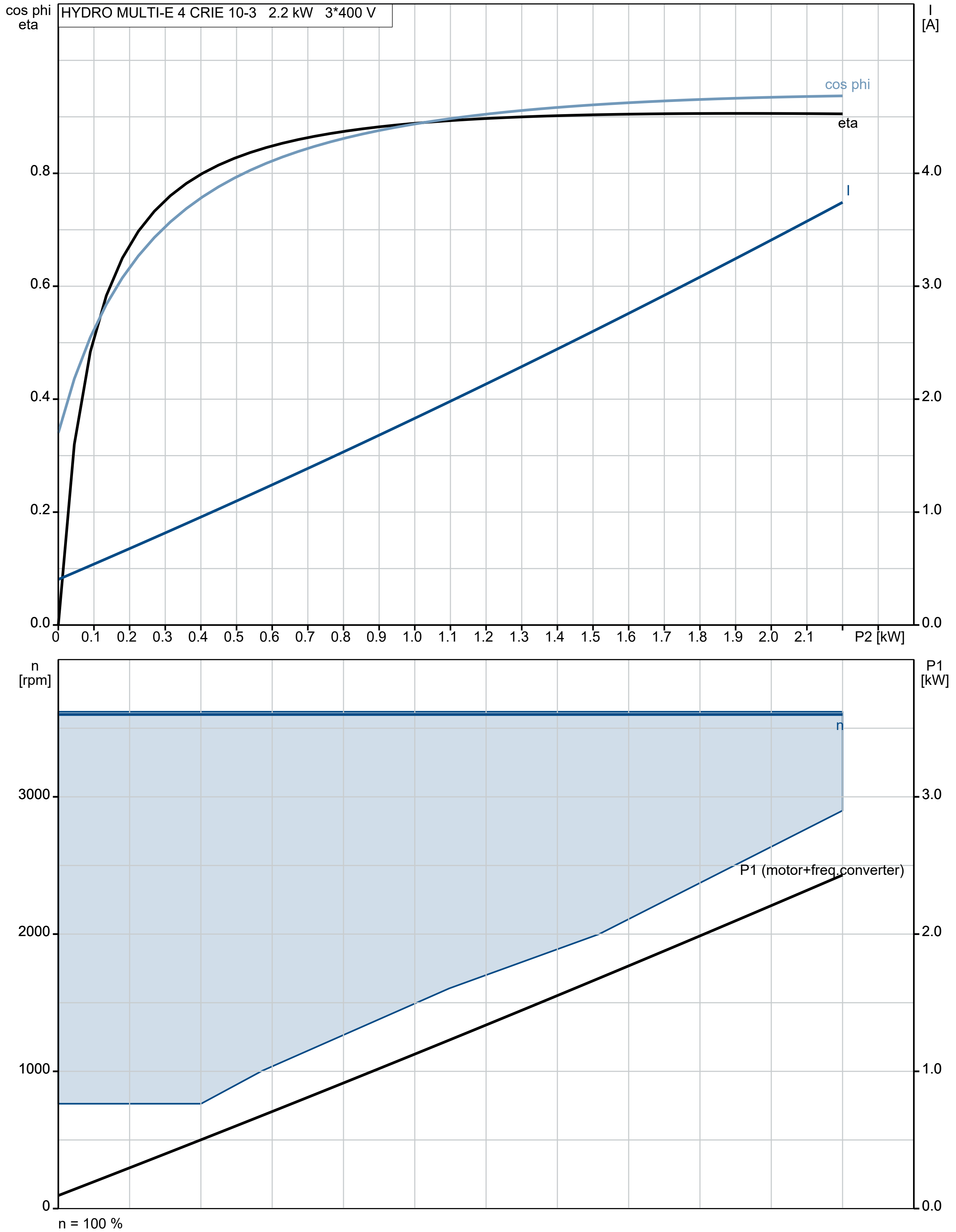
Losses in fittings and valves not included
Pumped liquid = Vann
Liquid temperature during operation = 20 °C
Density = 998.2 kg/m³



Company name: Grundfos
Created by:
Phone:

Date: 14/04/2023

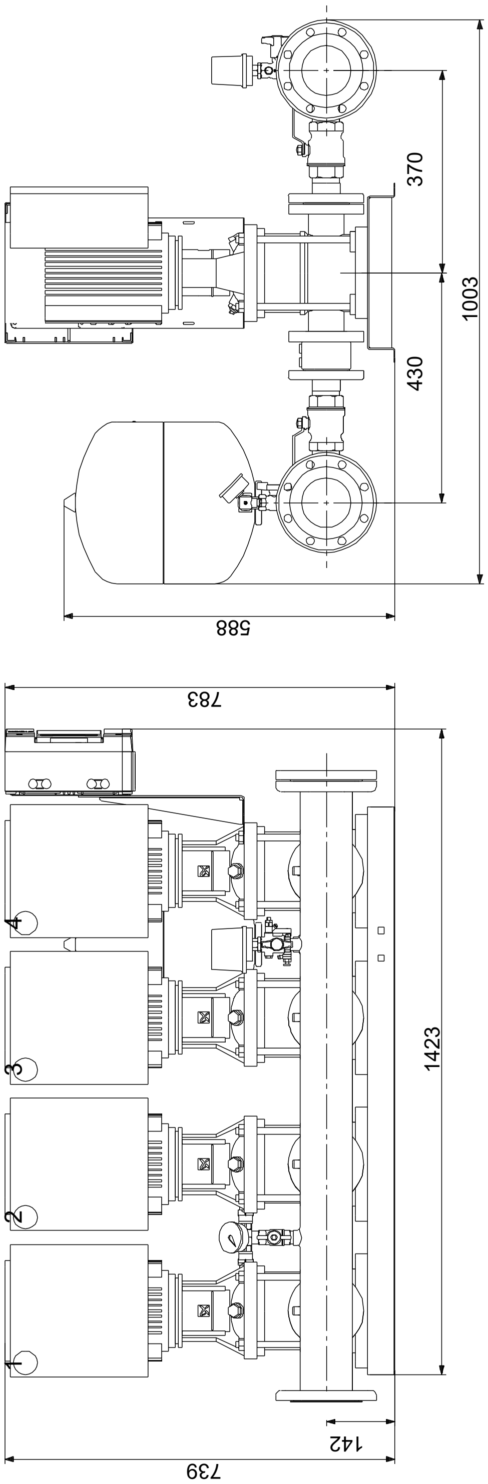
98486782 HYDRO MULTI-E 4 CRIE 10-3 50 Hz



Company name: Grundfos
Created by:
Phone:

Date: 14/04/2023

98486782 HYDRO MULTI-E 4 CRIE 10-3 50 Hz



Note! All units are in [mm] unless others are stated.
Disclaimer: This simplified dimensional drawing does not show all details.

A.16 Data Sheet Allweiler pump

CIRCOR | ALLWEILER®

Charact. curves
NB 32-125/01

Quotation / Offer No.	
Project ID	
Item:	
Pos.No:	
Created by	Date **2023-02-23**

Speed
3420 1/min

Charact. curves acc. **DIN EN ISO 9906:2013.03 3B**

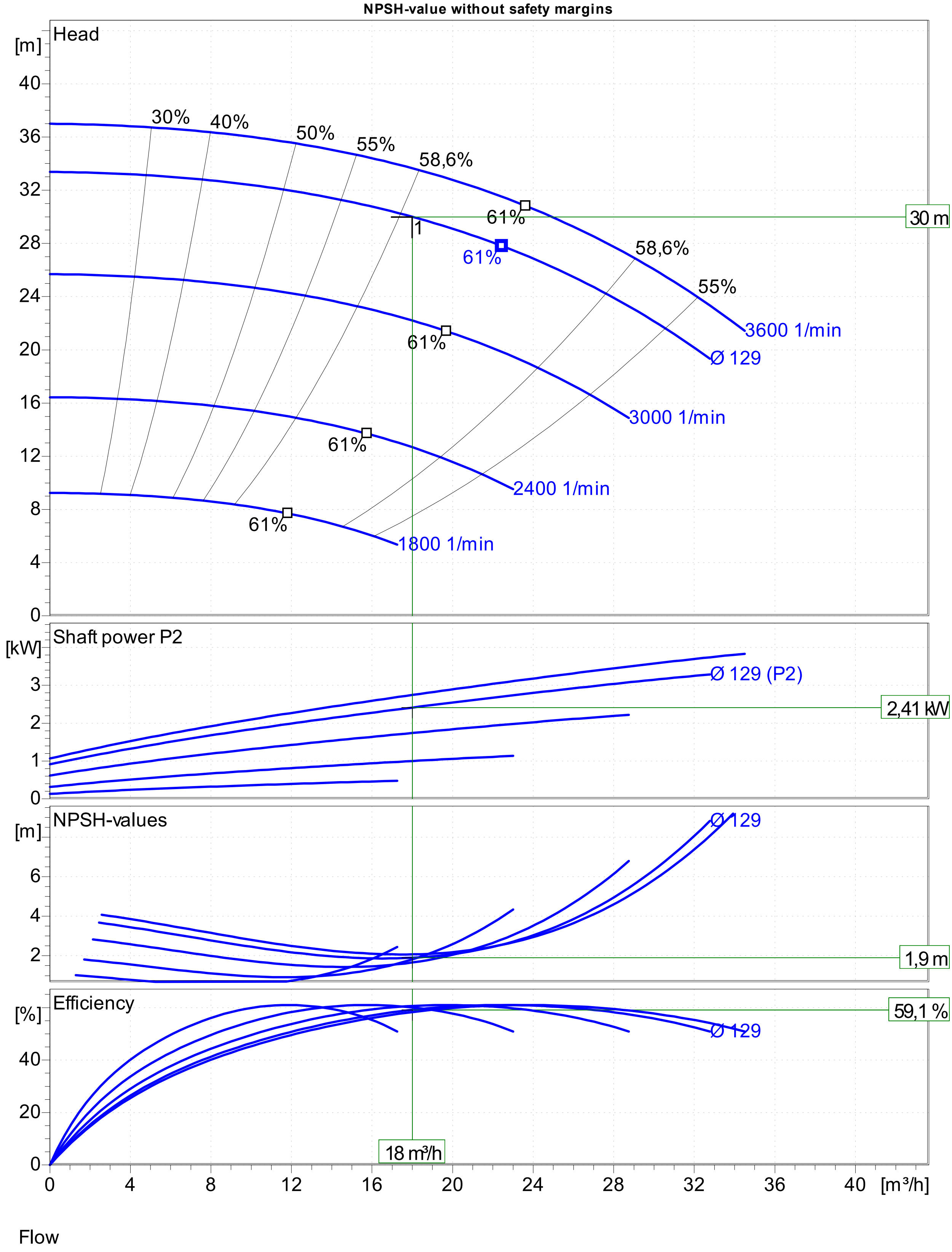
Minmum capacity at continous operation: **Qmin = 0.1 * Qopt**

Attention! At temperature t < -10°C please note materials!

Power data referred to: **Water, pure**

	Q	H	P	Vis	Temp	Density	rated Torque
1)	18,00 m³/h	30,00 m	2,41 kW	0,3 mm²/s	85,0 °C	0,97 kg/dm³	6,7 Nm
2)							

NPSH-value without safety margins



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Charact. curves
NB 32-125/01

Quotation / Offer No.	
Project ID	
Item:	
Pos.No:	
Created by	Date **2023-02-23**
Speed	**3420 1/min**

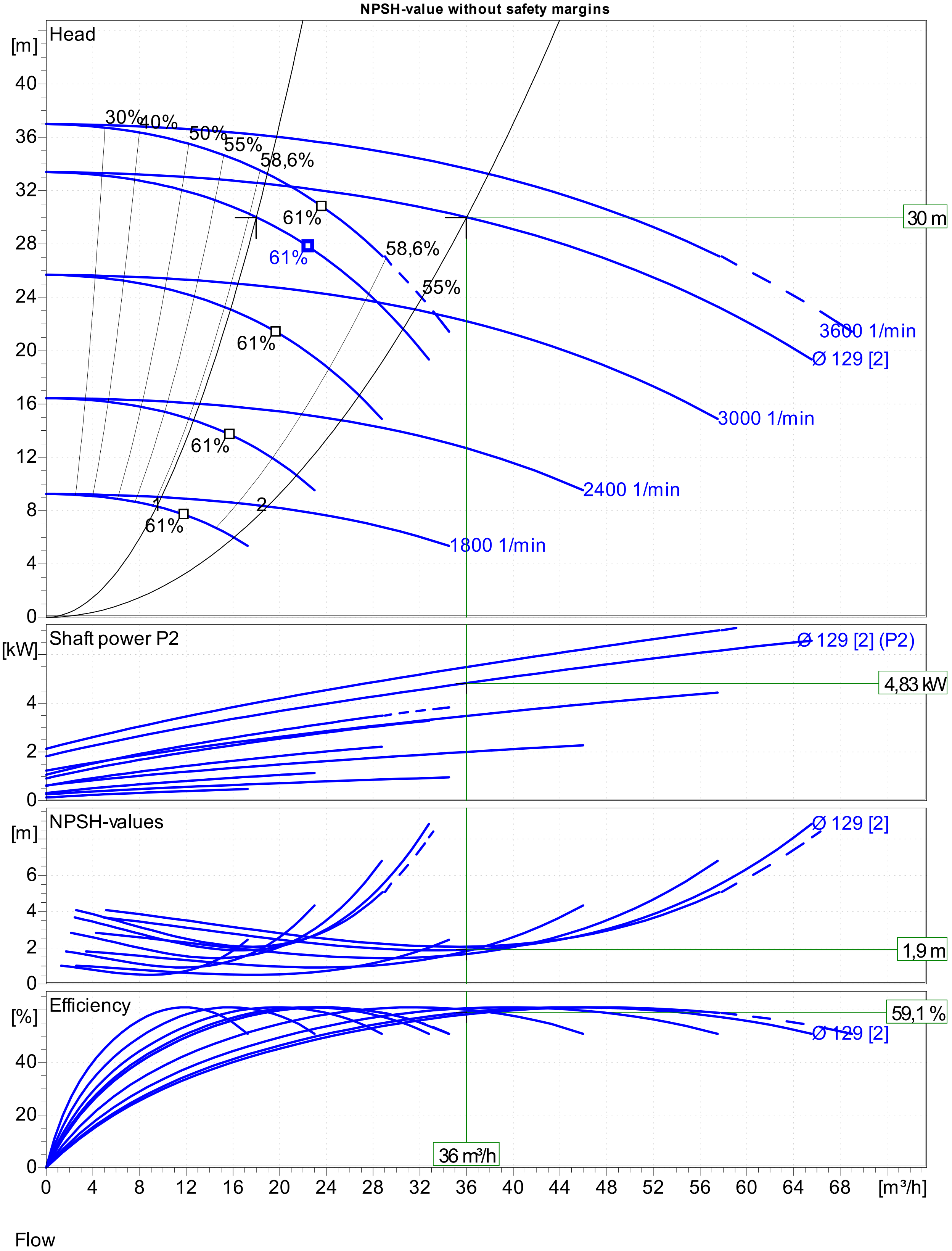
Charact. curves acc. **DIN EN ISO 9906:2013.03 3B**

Minmum capacity at continous operation: **Qmin = 0.1 * Qopt**

Attention! At temperature t < -10°C please note materials!

Power data referred to: **Water, pure**

	Q	H	P	Vis	Temp	Density	rated Torque
1)	18,00 m³/h	30,00 m	2,41 kW	0,3 mm²/s	85,0 °C	0,97 kg/dm³	6,7 Nm
2)							



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CIRCOR | ALLWEILER

Charact. curves
NB 32-160/02

Quotation / Offer No.

Project ID

Item:
Pos.No:

Created by

Date **2023-02-23**

Charact. curves acc. **DIN EN ISO 9906:2013.03 3B**

Minmum capacity at continous operation: **Qmin = 0.1 * Qopt**

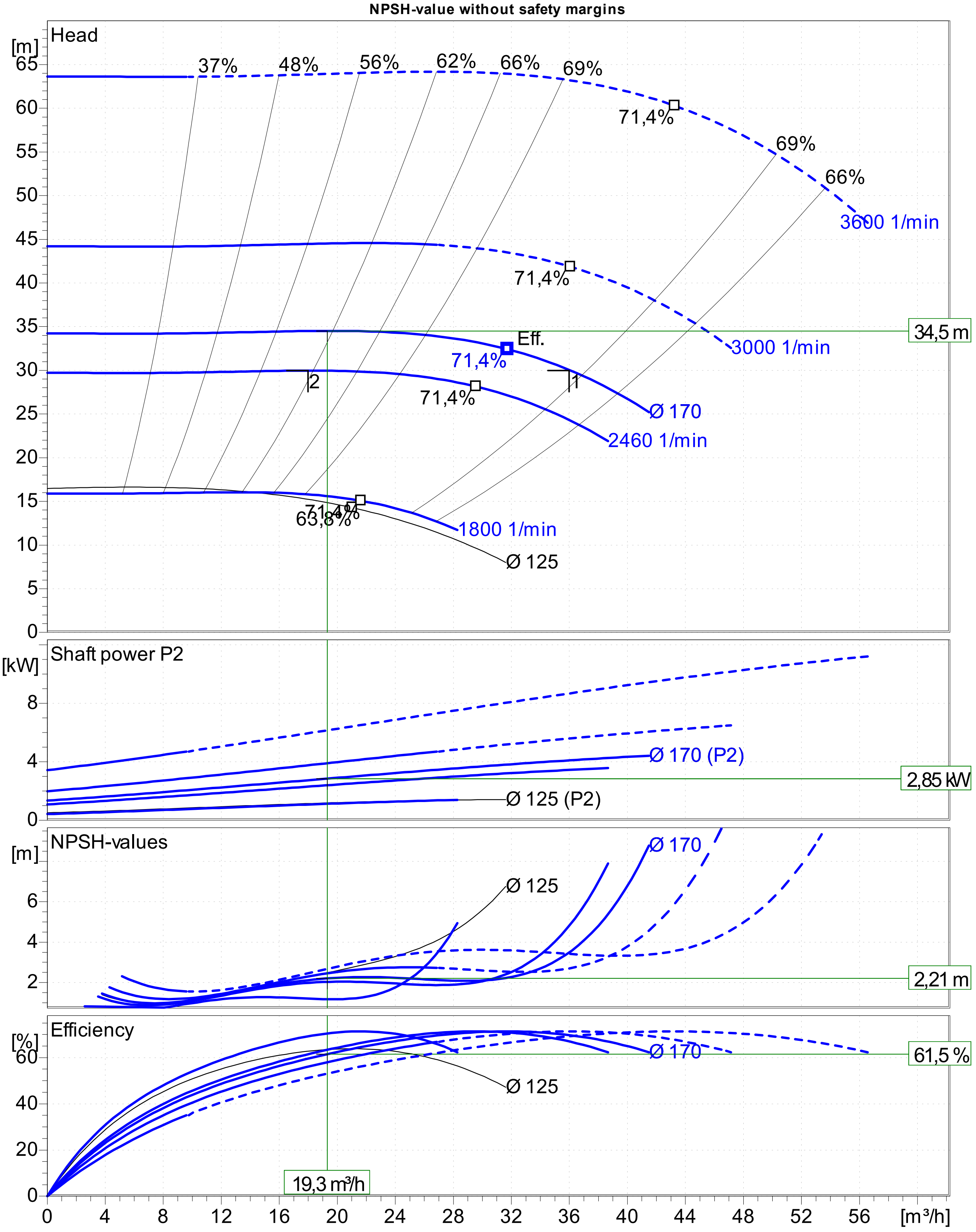
Attention! At temperature t < -10°C please note materials!

Power data referred to: **Water, pure**

	Q	H	P	Vis	Temp	Density	rated Torque
1)	19,31 m³/h	34,52 m	2,85 kW	0,3 mm²/s	85,0 °C	0,97 kg/dm³	10,3 Nm
2)							

Speed
2640 1/min

NPSH-value without safety margins



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NTNU
Norwegian University of
Science and Technology

VARD
a Fincantieri company