



# **Optimization of cooling for distributed electrical systems**

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# BACHELOR'S THESIS

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## Summary

This thesis work has been done for Wärtsilä Power Plants, Technology Department. The work was to examine different cooling systems and their functions, and to find a suitable alternative for Wärtsilä's newly planned low-voltage areas for power plants. The basic terms of air conditioning will be explained, and the different alternatives for cooling of the low voltage areas. The work also contains the necessary cooling calculations that were needed to determine the heat losses from the new low-voltage areas.

The electrical systems are currently placed in larger electrical rooms. The power distribution will, to a greater extent, be made more engine specific with these new solutions. This is to reduce material costs and to have less wiring in the engine hall. Two different low-voltage rooms have been planned, with different placements. The result of this thesis is two different alternatives for cooling of the low-voltage areas. One is a liquid-based system, while the other is air cooled. The alternatives can also use the same spaces to some extent. In this way the customer will have a chance to choose and both alternatives fulfill the requirements Wärtsilä has set.

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Language: English

Key words: air conditioning, heat losses, cooling calculations

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# EXAMENSARBETE

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Titel: *Optimering av kylsystem för distribuerade elsystem*

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## Abstrakt

Detta examensarbete har gjorts för Wärtsilä Power Plants, Technology Department. Arbetet gick ut på att undersöka olika kylsystem samt deras funktioner, och komma fram till ett lämpligt alternativ för Wärtsiläs nyplanerade lågspänningsutrymmen för kraftverk. Grundläggande termer för luftkonditionering går igenom, samt de olika alternativen för kylning av elutrymmena. Arbetet innehåller även de nödvändiga kylberäkningar som behövs för att kunna fastställa värmeförluster från de nya elutrymmena.

För tillfället är elsystemen placerat i större elutrymmen, men med dessa nya lösningar kommer eldistributionen att i en större utsträckning ske mer motorspecifikt. Detta är för att få ner materialkostnaderna samt mindre kabeldragningar i motorhallen. Två olika elutrymmen har planerats, med olika placeringar. Resultatet av detta examensarbete är två olika alternativ för kylning av elutrymmena. Det ena är ett vätskebaserat system, medan det andra är luftkylt. Alternativen kan även använda samma utrymmen till en viss del. På detta vis kommer kunden att ha en viss valmöjlighet och båda alternativen uppfyller de krav som Wärtsilä har ställt.

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Språk: engelska

Nyckelord: luftkonditionering, värmeförluster, kylberäkningar

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## Tiivistelmä

Opinnäytetyö on tehty Wärtsilä Power Plants, Technology-osastolle. Opinnäytetyössä tutkitaan erilaisia jäähdytysjärjestelmiä ja niiden toimintoja, jonka myötä löydettäisiin sopiva vaihtoehto Wärtsilän äskettäin suunniteltuun pienjännitealueelle voimalaitoksissa. Ilmastoinnin peruseriaatteet käydään läpi sekä erilaiset jäähdytysmenetelmät esitellään. Työ sisältää myös tarvittavat jäähdytyslaskelmat, jotka määrittävät uusien sähkötilojen lämpöahiöt.

Sähköjärjestelmä on tällä hetkellä sijoitettu isompaan sähkötilaan, mutta uusien ratkaisujen myötä sähkösiirto tulee laajemmin toimimaan moottorikohtaisesti. Tämä sen takia, että tarvikekustannukset olisivat pienempiä ja kaapelia kuluisi vähemmän. Kaksi erityyppistä sähkötilaa on suunniteltu erilaisilla sijoituksilla. Opinnäytetyön tuloksena on kaksi vaihtoehtoista menetelmää sähkötilojen jäähdyttämiseksi. Yksi on nestejäähdytetty, ja toinen on ilmajäähdytetty. Molempia menetelmiä voidaan käyttää tietyn tavoin samassa tilassa. Tämän myötä asiakas saa päättää, kumman menetelmän hän haluaa sähkötiloihinsa, molemmat menetelmät täyttävät Wärtsilän asettamat vaatimukset.

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Kieli: englanti

Avainsanat: ilmastointi, lämpöahiöt, jäähdytys laskelmat

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## Abbreviations

PPT	=	Power Plant Technology
MV	=	Medium Voltage
LV	=	Low Voltage
AC	=	Air Conditioning
BJA	=	Auxiliary system control panels
Genset	=	Generator set
CFC	=	Central Control panel, genset section
LFO	=	Light Fuel Oil
HFO	=	Heavy Fuel Oil
EAM	=	Oily water sewage
CBU	=	Compact Booster Unit
VFD	=	Variable Frequency Drive
HMI	=	Human Machine Interface

# 1 Introduction

This thesis has been made for Wärtsilä Power Plants, the Power Plant Technology department. Wärtsilä is a global company that designs and builds engines and power solutions for both marine vessels and power plants all around the world. The company has approximately 18 700 employees in nearly 170 locations in 70 countries. The company has three major parts: Ship Power for the marine area, Power Plants for power distribution and Service that offers support and installation for the other two areas.

Power Plants is a leading supplier of modern, environmentally advanced, highly efficient and dynamic power plants on the power market. They offer solutions for both oil and gas plants, and also multi-fueled plants that can run on both. [1]

The Power Plant Technology (PPT) department at Power Plants is responsible for the product development for the plants. It involves the development of both oil and gas plants. They are also responsible for the plant's performances and product portfolio. This work is done for the Electrical and Automation department of PPT.

## 1.1 Background

The power plants have two different electrical areas at this moment, the LV-room and the MV-room. These are monitored and controlled from the control room. The MV-room contains the plant's MV switchgear, outgoing connections and auxiliary transformer feeders. The LV-room contains the plant's LV-switchgears and supply to the engine auxiliaries. The MV-room can also be combined with the control room or the LV-room of the plant, depending on scope. Examples of current LV-rooms are available in appendix 2.

Many of the control panels that are located in the control room today can have their main functions carried out remotely via a computer. The LV-room is often placed in the middle of the plant or divided into two rooms at each end of the plant. In some cases all three rooms are combined into an electrical building in one end of the plant. This makes for unnecessary big buildings on the sites and often very long cable runs. All of this makes the electrical wiring very expensive. That is why a different solution may be needed in the future.

## 1.2 Upcoming changes

Wärtsilä has planned to reduce some of the wiring costs by making an electrical and automation module for each engine in the plant. This module will have the controls for the engine and does not need the operators' constant attention. The monitoring of the equipment will still be maintained from the control room. The costs of the electrical wiring will also be greatly reduced when wirings do not have to go through the whole plant. The module will be placed behind the engine, either indoor or outdoor. Both placement solutions have their pros and cons, which will be presented later in the thesis. To begin with will the new design be implemented in plants that use the 50SG/DF engines.

## 1.3 Target of the thesis

There are two alternative solutions for improving the LV-distribution. Wherever the equipment is placed, both rooms need cooling of some kind. The current cooling systems are not suitable for these smaller rooms in all cases, and standardization of a system would therefore be a good idea. The goal is to find suitable cooling solutions for the new LV-room, wherever it is placed. The two different solutions that Wärtsilä has opted for will be explained in greater detail in the theory, and their advantages compared to those of the old design. The theory will also contain basic information about cooling/heating systems for smaller buildings in general. There are a number of alternatives that are suitable for these rooms. There will be a basic explanation for a couple of them that are most likely to be used. The calculations and costs for the different choices will be presented as well as the choice that will be used in the end and the results of this thesis.

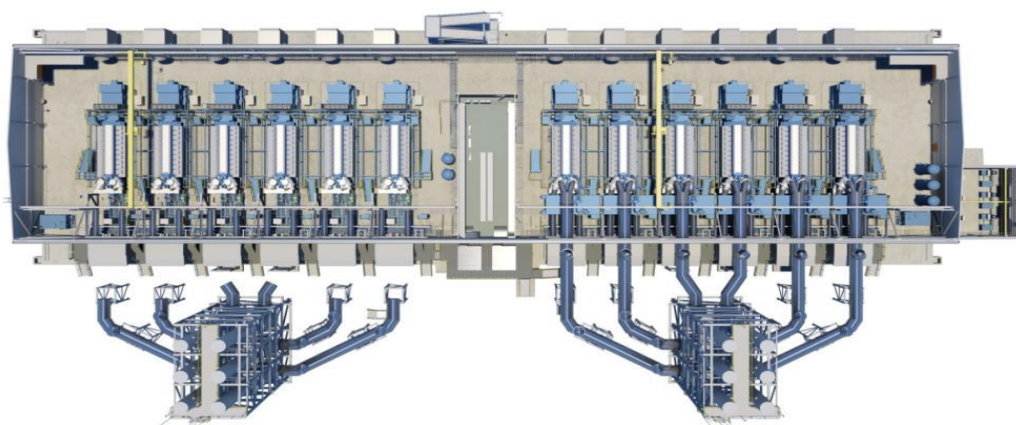
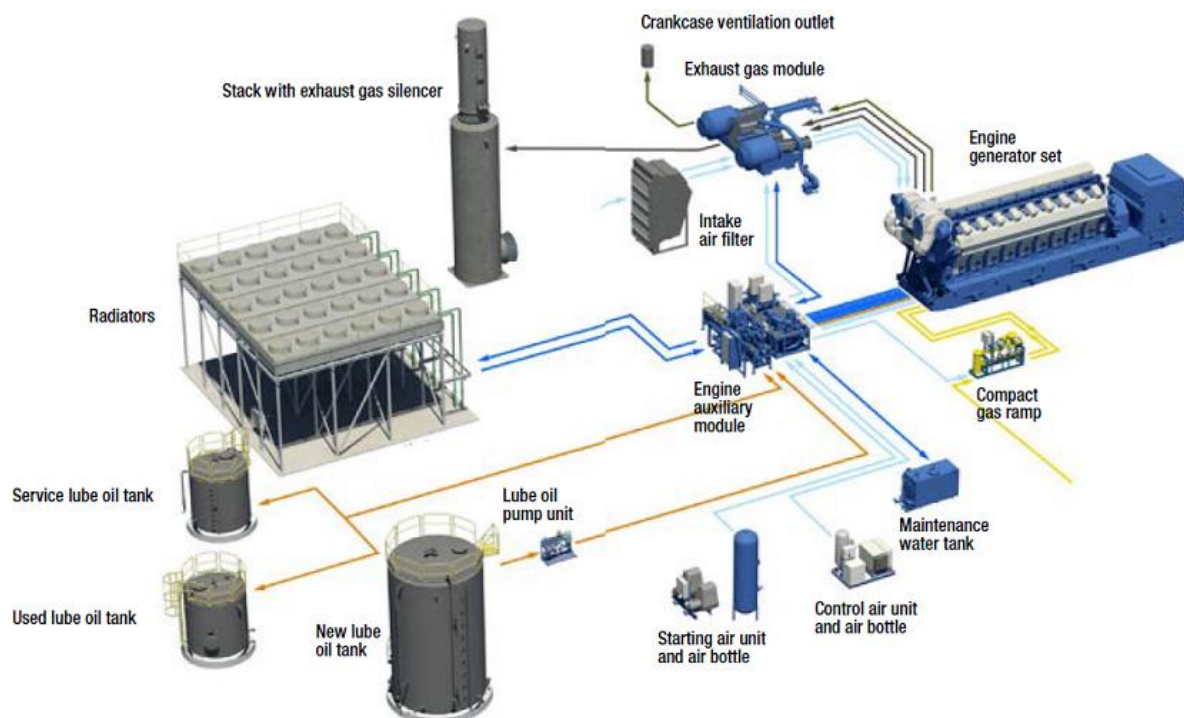


Figure 1. Power Plant with the LV-room in the middle [2]

## 2 Power Plants in general

Wärtsilä has a variable amount of solutions and sizes of power plants in their portfolio. Many are standardized, but new ideas are introduced and changes are often made, depending on the customers' needs. The main parts have the same placement in almost all cases.



**Figure 2. Main parts of a power plant [3]**

Figure 2 shows the components of the power plant and their connections. The components in this picture are connected to the LV-room. The connections to the MV-room are then after the generator set. The main part of the plant is the engine, which generates power to the generator. The generator then distributes the generated power to the plant's MW switchgear, which distributes it to the switchyard and out to the power lines and the customers. This is a simple description of how a power plant functions. The main focus will be on the auxiliary side, since this thesis mainly involves the connections in that area.

Most of the engine fuel systems, pumps and other electrical equipment are placed on the auxiliary module. The auxiliary systems provide functions for fluid handling and control, such as the lube oils, cooling and fuel connections. These are the main consumers of electricity on the engine, and they need many incoming connections. [3]

This is not a problem in smaller power plants, but the cable runs will be very long in larger plants with a centralized electrical LV-system. The cables that are used are often over dimensioned for the connections furthest away, and the cables used are quite expensive, due to their cross section. These LV-rooms are also often quite big and therefore need a large and expensive ventilation unit for the cooling of the equipment.

That is why a modular solution for the engine's LV-connections could be an alternative. Smaller rooms could be used for the needed equipment and placed more closely to the engines and use some sort of AC-units for cooling that can manage the heat from the surroundings and the equipment. This saves costs in both cooling equipment and cabling to the engines.

### **3 Power Plants alternatives**

Wärtsilä has come up with two different alternatives to make the changes possible for the LV-systems. The options would be two smaller LV-rooms to choose between, one that can be placed outside the power plant, and one that can be placed inside. Both have their pros and cons.

#### **3.1 Benefits**

The two solutions that Wärtsilä has considered will not make any major changes in the site design, but greatly reduce the electrical cable runs and also the total electrical wiring costs. The two alternatives have a slightly different design but will contain the same amount of electrical cabinets. The modules will contain all LV equipment for the genset of the engine and the control panels. The auxiliary system control panel's (BJA) controls will be moved from the engine hall and the central control panel for the genset section (CFC) from the control room.

Many of the current electrical installations generate much heat in the LV-room, and the largest producers are the engines' VFDs (Variable Frequency Drive). These will not be placed in the new LV-rooms due to limited space and heat production, since the new rooms will be much smaller. Instead the VFDs will be placed on the roof under the radiators so that they can still be close to the engines and at the same time, get some heat out of the hall.

The DC-system will be split in to two separate parts, one engine-specific DC that will be in the new LV-room and the other DC-system will be placed in the electrical auxiliary room in the control building. Other incoming cables and feeders will come from the LV-room that is used today. Some equipment will be placed in a common LV-room that supplies the engine hall (LFO/HFO pumps for example).

The benefits with these new models are many. To begin with, the main control room does not need to be as big as before and therefore it saves both space on the site and building material. All the panels that have been moved can be controlled remotely. It is also easier for the operator when all necessary data can be monitored from the same HMI panel. The components in table 1 are the ones that have their connections moved to the new LV-room.

**Table 1. BJA controls/suppliers that moves to the new module [4]**

<b>BJA 0_1</b>	<b>W50DF EAM + CBU CONTROL PANEL</b>
MOD 0_1 M004	Prelube Pump Motor
SCA 0_1 M001	Turning Gear Motor
BAG 0_1 B001	Generator Anticondensation Heaters
SCA 0_1 E101	Engine leak fuel trace heating
BLU 0_1	Charge Air Filter A Control Panel
BLU 0_2	Charge Air Filter B Control Panel
NHA 0_1 M001	Engine exhaust gas ventilation fan
PCA 0_1 M001	Booster Pump Motor
PCA 0_1 M002	Clean Leakage Pump Motor
PCA 0_1 B017	Electrical Trace Heating for CBU Fuel & Sludge lines
PCA 0_1 B016	Electrical Trace Heating for Pipe Rack
BJA 0_1 A013	Engine torsional vibration monitor
BLS 0_1	Oil Mist separator panel
BJA 0_1 E001	Outlet Socket
<b>BJA 0_2</b>	<b>HT WATER PREHEATER PANEL</b>
VDA 0_1 B001.1	Heater Step 1
VDA 0_1 B001.2	Heater Step 2
VDA 0_1 B001.3	Heater Step 3
VDA 0_1 B001.4	Heater Step 4
VDA 0_1 M001	Preheating Circulation Pump Motor

The protection relays will not be placed in the new module but will be located in a relay panel in the MV-house. Cablings to the MV-house will also be reduced as some components move. The AC consumption will be less as the new E&A room is not manned and can have a slightly higher temperature. The rooms are not affected either to the same extent from outdoor temperatures and heat losses, since there are no windows.

Today, the customer can choose if he wants the LV-equipment to be supplied by Wärtsilä or by a different supplier. At this point there is still no other supplier of these new models that are designed for Wärtsilä power plants. This might look as if it is all for Wärtsilä's benefit, but hopefully the customer sees the benefits with lower material costs and stable power solutions despite the limited range of suppliers.

A problem that can occur is redundancy of the system. This is a very important factor to Wärtsilä and has to be controlled before choosing the cooling equipment. Some small surplus may be allowed, but not in a longer run.

The designs for the electrical cabinets that will be used in this thesis are supplied by two of Wärtsilä's control system suppliers. Their designs for the room vary in some aspects, but there are no major changes and both solutions work in accordance with the same standard.

### **3.2 Solution 1: Indoor module**

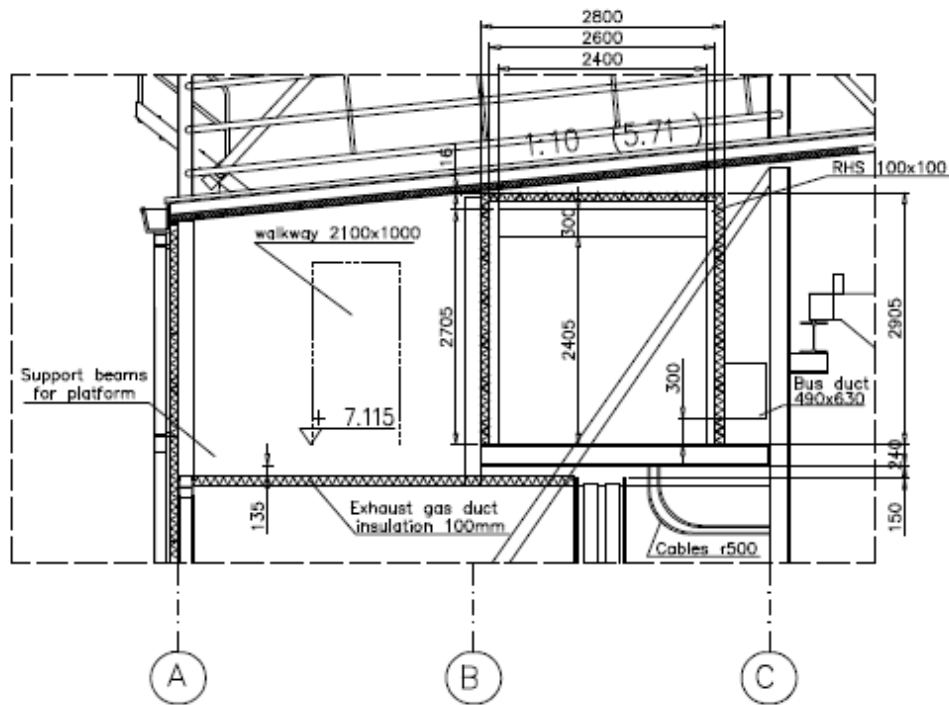
The first solution is based on a module that will be placed inside the power plant. It will come above the exhaust ducting in the auxiliary area of the engine hall. This module is slightly smaller than the second alternative, in which the electrical cabinets come on both sides. It will be approximately  $7.3 m^2$ .

There will be no major changes in the construction for this alternative, but the space where it will be placed is quite tight, since there is a lot of equipment below and it will be close to the roof. A new platform and ladders are also needed for access to modules. Some support structures for the room also need to be included.

This room will be exposed to a constant heat from the engine and the exhaust gas module. Therefore, the temperature will be quite high around this room. It can be as much as 50-60 °C, so the cooling must have a high efficiency in this area. The cooling for this alternative has to be some kind of split-unit since the room will be inside the engine hall.

The advantage with this module is that it is not affected by outdoor temperature or weather. That is helpful when calculating the cooling needs. External factors, such as rain, snow or any weather condition, do not need to be considered.

The module will not be exposed to direct sunlight either, which has a major impact on inside temperatures in some areas.



**Figure 3. Placement of module indoor (side view)**

The module will be placed close to the ceiling as seen in figure 3. The module is the part in the middle of the picture. The marked space between the outer wall and the module is where the new access walkway will be placed.

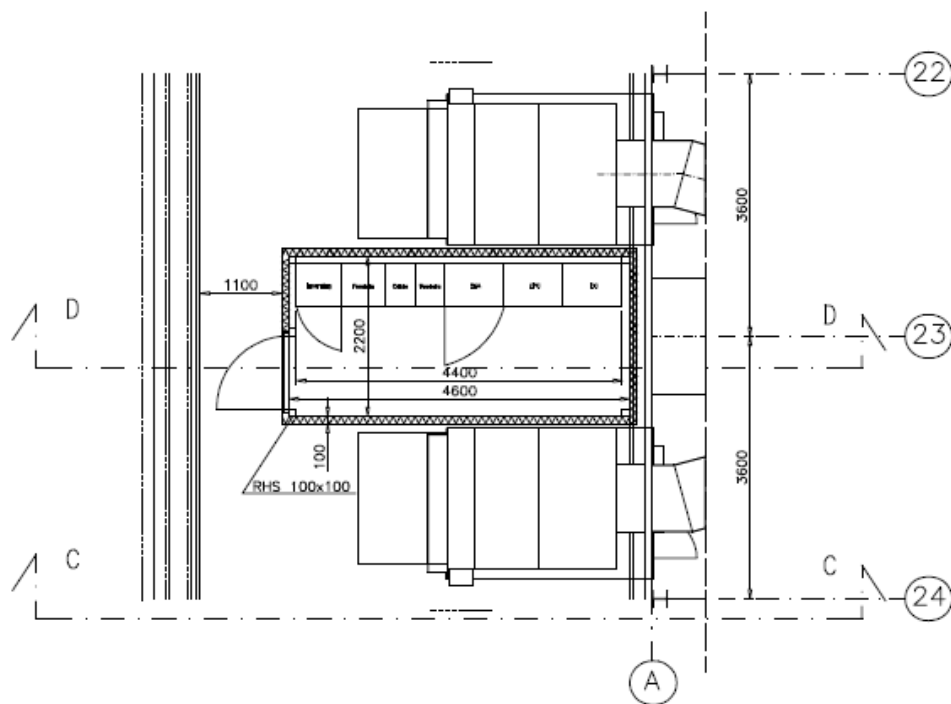
### **3.3 Solution 2: Outdoor module**

This alternative is slightly different from the first. It is bigger as all the electrical cabinets are on the same side of the room. It will be approximately  $10.35 m^2$ . The only logical place for these rooms is as close to the engine as possible, which means they are placed with the short side directly against the outer wall of the plant between the charge air filters. Since the module will be placed where the current auxiliary ventilation unit is placed, some changes will have to be made.

The engine's ventilation unit will be separated into two units instead of one. This is because the old auxiliary side ventilation unit was larger and in the same spot as the outdoor module will be placed. The demand will be filled with these two smaller units as well, and the costs do not vary that much between the two smaller and one big ventilation unit.

The charge air filter will also be moved a bit higher up than it is today, and the exhaust stack will come 1400 mm further out from the plant. Access to the room is possible from the same platform as is used to maintain the ventilation filters, the platform only stretches a bit further out with the new design, about 1650 mm.

Some changes in the construction of this module may be needed to be able to manage the outdoor conditions. The roof will probably have a different plating to sustain rain and snow. This one will also be exposed to direct sunlight most of the day, which raises the indoor temperature. But as said earlier, windows are not needed and will therefore not affect the room's temperature.



**Figure 4. Placement of outdoor module (top view)**

Figure 4 shows how the module is placed between the new ventilation units. The access walkway to the ventilation will be extended to maintain the room's access too. All electrical cabinets will be on one side of the room.

Regardless of the way the module is built, it saves much space on the site area. Both alternatives save around  $1185 \text{ m}^2$  on the site, which can be significant in some cases. This area is not yet a 100 % given, the detailed design is still under development until the delivery stage.

Layouts for both alternatives are available in appendix 3.

## 4 Basic theory about cooling systems

The theory for cooling and ac units is extensive, so only the basics needed for understanding this thesis and its contents will be explained. The calculations that have been used to get the necessary values are available for use on the website of the Ministry of Environment.

### 4.1 Air conditioning in general

Air conditioning can refer to any form of mechanical cooling, heating, ventilation or disinfection that modifies the condition of air. It can be a smaller or major system depending on the amount of air that the system is to change within a specific area.

Cooling is typically done by using a simple refrigeration cycle, but it can also be done through evaporation. It is commonly used for comfort cooling of buildings and equipment /engines that needs cooling.

All air conditioning units utilizing the refrigeration cycle have four major parts:

**Evaporator** – receives the liquid refrigerant

**Condenser** – facilitates the heat transfer

**Expansion valve** – regulates the refrigerant's flow into the evaporator

**Compressor** – a pump that pressurizes the refrigerant

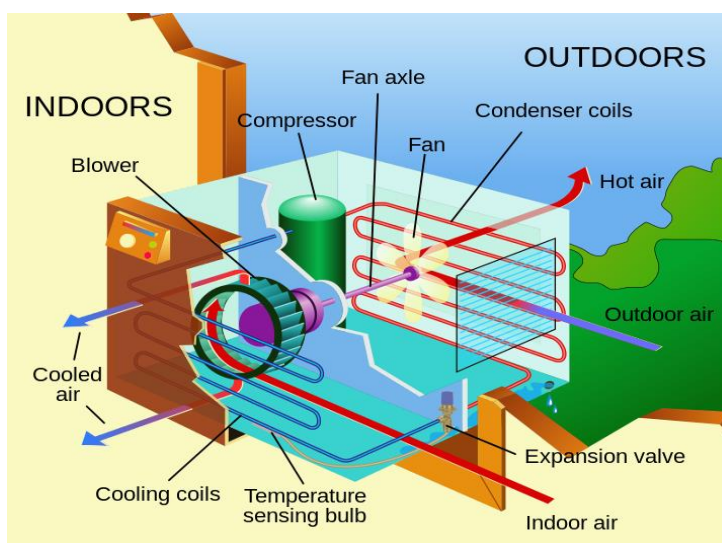
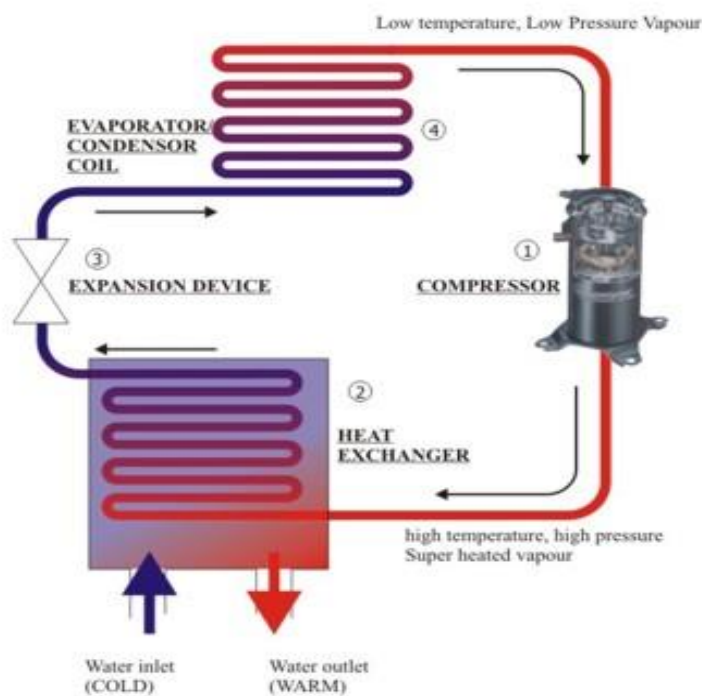


Figure 5. A typical air conditioning window unit (Components explained earlier are all mounted in a box that is installed in the window on these specific models) [5]

The refrigeration cycle works by a heat pump that transfers heat from a lower-temperature source into a higher-temperature heat sink. The heat will then naturally flow in the opposite direction and out of the space that needs cooling.

This is done by a liquid refrigerant that evaporates and condenses in coils over and over again in a closed system. When hot air flows over the compressed refrigerant in the coils, it starts to absorb heat and changes into a gaseous state. The gas is then led out through another set of coils to an expansion valve. At the same time the extra heat from inside is led out the same way and released outside. When the gas expands and cools, it changes to a liquid refrigerant again and the process restarts.



**Figure 6. Typical cooling concept [6]**

Figure 6 shows the cooling cycle and can be explained like this: liquid refrigerant > compression > gas/heat absorption > condensed > liquid refrigerant > cycle restarts

This is the typical cycle for all models of heat pumps/split units. [7]

## 4.2 Refrigerants

Refrigerants are an important part of the cooling cycle and have an impact on the cooling capacity, depending on which type is used. Refrigerants are chemicals that are combined for their different qualities and needs. These are then assigned an R number that is given according to the chemicals molecular structure. There are several different refrigerants, but only the more common ones are used by Wärtsilä.

**Table 2. List of refrigerants**

Refrigerants	Used by Wärtsilä
R-407C	Yes
R-410A	Yes
R-134a	Yes
R-22	No

R-134a is more common in AC for human comfort, while the others are more for industrial use. Both R-407C and R-410A are developed to replace R-22. R-22 is banned in the whole of Europe and by Wärtsilä, due to its effects on the ozone layer. It is still commonly used in South and Central America. [8]

## 4.3 Basic calculations

Since these new alternatives do not work as a normal living space, there are some factors that can be ignored. The room does not need windows and the temperature inside the rooms will not be affected by different fluctuations (only one door, human presence is not constant). The effects of the electrical equipment will mostly be the same all the time, since the same controls will be running.

The things that affect the calculations are the outside temperature, wall material and thickness, heat losses through walls /doors and heat from the electrical equipment.

Direct sunlight will have an effect on the module that will be placed outside, but the calculations that have been made will take that into account due to the high temperatures that have been used.

An important factor when heat losses are calculated is the heat transfer coefficient for the materials. This value tells us the difference between the heat flux and the thermodynamics that force the flow of heat.

The formula for this value is:

$$h = \frac{q}{\Delta T}$$

where:  $h$  is the heat transfer coefficient

$q$  is for heat flux,  $W/m^2$  (thermal power per unit area)

$\Delta T$  is the difference in the temperature between the surface and the surrounding area. [9]

This value ( $h$ ) is always given by the supplier of the building for each type of material that is used for insulation and is more commonly known as the material's U-value. The materials that will be used for construction have their coefficient given in U-value.

The U-value is the overall heat transfer coefficient that tells how well a building material conducts or transfers heat (in watts) through one square meter of a structure, divided by the temperature difference inside the structure. It is necessary to know how big the heat losses will be between different materials.

The U-value can be calculated with the formula for  $h$ , but the easiest way to calculate U is  $U = 1/R$ , where R is the thermal resistance in different materials. [10]

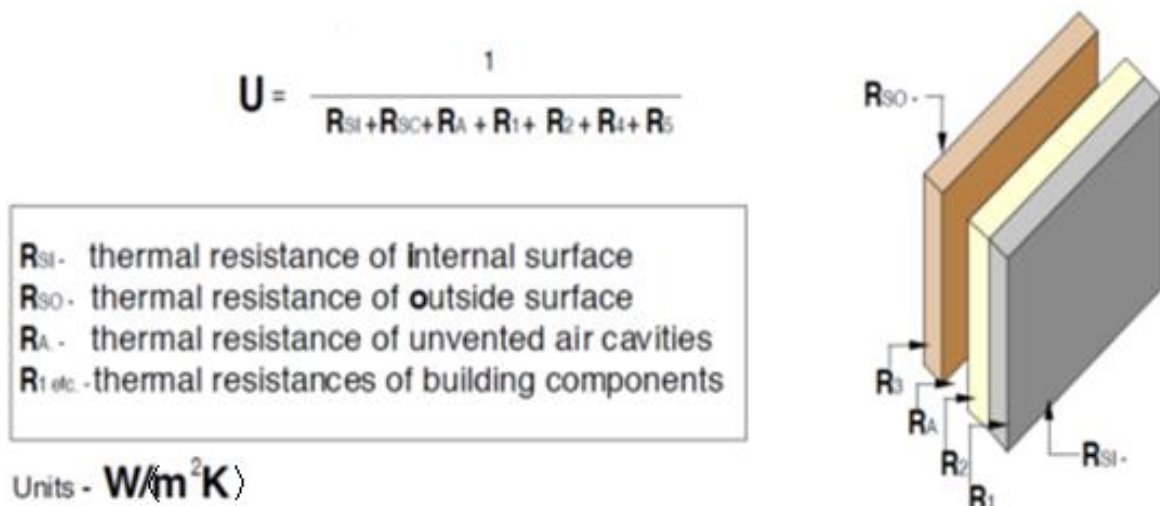


Figure 6. U-value calculations [10]

Other calculations that are used are the ones for overall heat losses through all parts of the structure. The need for compensation of heat losses is calculated separately for each part of the building before the calculation of overall losses.

This is done with:  $\Phi_j = \sum U_i \cdot A_i (T_s - T_{u,mit})$

where  $\Phi_j$  is the need for compensation of heat losses, W

$U_i$  is the heat transfer coefficient,  $W/(m^2 \cdot K)$

$A_i$  is the structure's area,  $m^2$

$T_s$  is the inside temperature, °C or K

$T_{u,mit}$  is the dimensioned outside temperature, °C or K [9]

When all of these are known it is possible to calculate the overall heat losses.

The formula for this is:

$$\Phi_{total} (W) = \Phi_{out} + \Phi_{f,r} + \Phi_w + \Phi_d + \Phi_{temp} + \Phi_{thermal}$$

where  $\Phi_{out}$  is outer wall losses

$\Phi_{f,r}$  is floor and roof structure losses

$\Phi_w$  is window losses

$\Phi_d$  is door losses

$\Phi_{temp}$  is temperature differences

$\Phi_{thermal}$  is thermal bridges

All these calculations are needed for the determination of the heat losses. A Microsoft Excel file that includes all these calculations included was available for use. It is used for this very purpose by Wärtsilä internally.

## **5 Cooling solutions and equipment**

Several different types and solutions of chillers and split-units were considered before the final decisions were made. The decision regarding these solutions was taken on the basis of the sustainability and the capacity of the cooling systems, their availability in different areas and their installations and service needs.

### **5.1 Chiller**

Chiller is a cooling system that removes heat from a liquid via a vapor-compression cycle. The system follows the basic cooling cycle. It works by utilizing a liquid refrigerant that changes to gas within an evaporator which absorbs heat from the water to be cooled.

The gas is then compressed to a higher pressure by a compressor or a generator, converted back to liquid by rejecting heat through a condenser and then expanded to a low-pressure mixture of liquid and vapor that goes back to the evaporation section and repeats the cycle.

It is used in both air conditioning and industrial cooling. In industry the liquid is pumped through process machines and other equipment that needs cooling. In this way it is achieving the highest efficiency. A byproduct from the refrigeration cycle is waste heat that has to be exhausted, or also it can be recovered for heating purposes. [11]

There are different types of chillers, but the only applicable type for Wärtsilä's use is the one that works according to the vapor compressor cycle. The cycle works on the same basis as explained in chapter 4.

### **5.2 Split units**

The split unit systems are one of the more common ones that are used for cooling today, since almost all heat pumps are of the split-type. These are usually the types that you see outside people's houses. As the name says, this system is built up of two parts: one outside module (condensing unit) and one inside (heat exchanger).

Most of these units just cool a single room or a smaller area, and not an entire house. There are different types available: the ones for cooling only and heat pumps that can both cool and heat. The heat pumps are the more common ones.

The hoses that go between the two units consist of insulated copper pipes that transport the refrigerant liquids. These are flexible and can therefore increase the distance to the outdoor unit and hide it out of sight if needed. An important factor when choosing these units is what type of refrigerant to use. Normally these units cannot manage to heat an area very well if the temperature drops below  $-20\text{ }^{\circ}\text{C}$ . Depending on the refrigerant chosen, the unit can still work properly at lower temperatures.



**Figure 8. Typical split-unit AC (left) and Chiller unit (right) [6]**

The coil sides are separated in split-systems. The coils that dispose of the heat are on the outside and the cooling coils are on the inside. The function is much like the one for chiller units, except that these types do not use water for heat absorption. Split systems use two sides, the evaporator and the condensing unit.

The evaporation side consists of the expansion valve and cold coils, and it is usually placed in an air handler that distributes the cooled air to a preferred area.

The second unit is then placed outside the building and works as the condensing unit. These two are then connected with a long tube that contains two copper pipes and a cable. The pipes transfer the heat to be vented outside and the refrigerant between the modules for the cooling process. [12]

### 5.3 Wall units

Wall units work according to the same cooling process as split units. The only difference is that hot and cold sides are separated and the cooling capacity of the split unit is a little higher. They are installed either in a window or directly on the wall where a hole is made for the indoor part. The installation of wall units can be difficult sometimes, depending on the placement of the unit. There can be a problem with the placement, if there are many wirings and conduits in the walls.

## 6 Calculations and costs

The heat losses will vary depending on the placement of the rooms, and they are therefore of high importance when choosing the right option for cooling. The calculations have been made with the available data for both rooms. The prices that are used are from Wäertsilä's own material lists of cost calculations. Since this is a pilot idea, no final prices are yet given. Therefore the results may come to differ in the end, but not significantly.

### 6.1 Module calculations

The calculations needed were the ones for heat losses from the new rooms and the heat distributed from the electrical equipment inside. The expected heat outputs were given by both suppliers for each of their electrical cabinets. An Excel table from Wäertsilä which is used to calculate the heat losses for the different buildings on the plant site, was available for use. The table has all the needed formulas for calculations inserted. The necessary data was the measurements of the new rooms, the expected heat differences and the heat coefficient. Another thing is that the modules do not need windows, which waste heat. Heat losses as a total and per  $m^2$  could then be calculated with given values.

The calculations for the two rooms area are as follows:

#### Outdoor electrical module

Height to roof:  $2.7\text{ m}$

Floor area:  $2.2\text{ m} \cdot 4.6\text{ m} \approx 10.35\text{ m}^2$

Area:  $(2 \cdot 4.6\text{ m} + 2 \cdot 2.2\text{ m}) \cdot 2.7\text{ m} = 36.72\text{ m}^2$

### Indoor electrical module

Floor area:  $2.6 \text{ m} \cdot 2.8 \text{ m} \approx 7.3 \text{ m}^2$

Area:  $(2 \cdot 2.6 \text{ m} + 2 \cdot 2.8 \text{ m}) \cdot 2.7 \text{ m} = 29.16 \text{ m}^2$

The same wall panels were used for both calculations, namely Ruukki panel SPA-S 100 mm. The U-coefficient for these panels is  $0.44 \text{ W}/(\text{m}^2 \cdot \text{K})$

The heat outputs that are given by both suppliers of the electrical cabinets are the following:

**Table 2. Electrical effects**

Indoor effects	W
Supplier 1	3440
Supplier 2	3800

These heat loads can vary somewhat in the end, but not in such a way that they have a major impact on the calculations that have been made.

Values in the tables were given by Wärtsilä's Excel table for heat losses calculations for cooling capacity needs. A cutout from the table will be available in the appendix 1.

From the area calculations and formulas in chapter 4.2 and with the use of the Excel chart, the following results were obtained:

**Table 3. Outdoor calculations**

Outdoor room	m2		
Area	36.72		
floor area	10.35		
Temp. Indoor (C)	Temp. Outdoor (C)	Heat losses (W)	W/m3
20	-40	1537.8	55.03
20	-30	1289.2	46.13
20	-20	1040.7	37.24
20	-10	792.2	28.36
20	0	543.6	19.45
20	10	295.1	10.56
20	20	46.6	1.67
30	30	46.6	1.67
30	40	-202	-7.23
30	50	-450.5	-16.12

**Table 4. Indoor calculations**

Indoor room	m2		
Area	29.16		
floor area	7.3		
Temp. Indoor (C)	Temp. Outdoor (C)	Heat losses (W)	W/m3
20	20	32.9	1.67
30	30	32.9	1.67
30	40	-166.3	-8.44
30	50	-365.4	-18.54
30	60	-564.5	-28.64
30	70	-763.7	-38.74

Many temperature differences were compared to get a better picture of how much the heat losses may change in different conditions.

Since the rooms are quite small, the heat losses will not be that significant. Roughly speaking, the heat from the electrical equipment will be enough for heating. If heating is needed in any case, a simple electrical heating element will be sufficient for the needs.

The cooling systems that were chosen will have to manage to cool around 4.4 kW in the most extreme cases (maximum output from equipment and temperatures above 60 °C). Most of the manufacturers today make models that can easily handle these heat outputs. Anyway, a number of different solutions have to be considered for different sites, depending on the environment.

## 6.2 Cost comparisons

The overall savings that can be made on LV-wirings is significant, but for the ventilation wiring it will not have a big impact. The main difference will be on smaller plants. Some small price comparison calculations were made, but there is no big difference between the prices for the different solutions. As mentioned before, there are not any big changes in the prices of ventilation wirings. The major savings will instead be in the wirings for each engine, since there is no need for wirings from a central LV-room. These savings will not be included in this thesis, since they are confidential information and the thesis concentrates on the cooling techniques.

### 6.2.1 Cabling costs

Since the size of the LV-rooms that are used today is quite big, great demands are made on the ventilation unit's performance. These units are then often quite expensive. Some savings can be made with these new smaller units and modules. The comparisons are made between split-units, the chiller system and the current system.

Example: Ventilation wirings for a 12xW18V50DF power plant.

**Table 5. Wirings dimensions and prices**

Options	Cable length (m)	Cable dimensions (mm)	Price (€/m)
Split-unit	15 per unit	3x2.5	2.9
Chiller	60	5x6	4.5
Current ventilation	45	5x35	15

The estimated wiring lengths are taken from power plant layouts for the plants in question. There are given lengths of the wirings, but they may vary between different plants. These lengths are within the limits that are accepted.

Prices:

Split:  $2.9 \text{ €/m} \cdot 15 \text{ m} \approx 45 \text{ € per unit}$ ,  $45 \text{ €/unit} \cdot 12 \text{ units} = 540 \text{ €}$  for the ventilation wirings of the whole plant

Chiller:  $4.5 \text{ €/m} \cdot 60 \text{ m} = 270 \text{ €}$  to central unit

Current system:  $15 \text{ €/m} \cdot 45 \text{ m} = 675 \text{ €}$  for ventilation cablings

The differences between the wiring costs are not that big compared to other costs, mainly because of the length of the wirings for the current system. The prices rise rapidly when the cabling's diameter exceeds 35 mm, and since the current system only needs about 45 m of cabling compared to the new system that needs much longer cabling with a smaller diameter, the prices are quite even. The prices that are used in this comparison are from Wärtsilä's own price lists that are used for cost calculations. The prices are for the Finnish market and follow the Haahtela index. This index is from a Finnish company that specializes in project management for construction projects and construction finance. The index may vary between different countries. [13]

### **6.2.2 Ventilation unit costs**

To get fixed comparisons between prices for the ventilation units that are used in the LV-rooms today and the new models is not possible, since different units are used for almost all projects. The prices vary from 500 € to over 10 000 €, depending on the units and locations.

The prices for the new units will also differ between the different options chosen. These will be presented in more detail in chapter 7.2, where the comparison between the two options will be presented.

Based on given estimates, another price change worth mentioning is the one for the engine's auxiliary ventilation unit, since it is split in the outdoor alternative for the E&A room. The standard current ventilation units cost approximately 12 300 € per unit. The new units work as a split system and will cost 7500 € each. That would mean a price of 15 000 € per genset. The price rise of the ventilation in this alternative will be 2700 € per genset. That could mean some noticeable changes in the prices of large power plants.

## **7 Choice of equipment**

After necessary calculations and checking of available info, two suitable systems have been chosen for the two types of modules.

The decision fell on two alternatives that could use the same indoor spaces: one chiller system and one for split-units. It was decided to use the same kind of ventilation indoor unit for both alternatives so it can be standardized if needed. The outlet chosen is of the cassette type. This type of outlet is placed in the ceiling, in the middle of the room. A main idea was to put two cassettes in the ceiling, mostly to use one as a backup if needed. These kinds of outlets were chosen because there are a lot more of them available for the chiller systems compared to wall-mounted types. They do not take up much space either. All models are similar and are approximately 600x600 mm in size, which leaves much space available for both lights and other equipment that may come in the future.

The systems can be used for both cooling and heating, even if cooling is their main purpose. Both units have been chosen while taking service needs into account.



**Figure 10. Cassette outlet. Air flows in all directions [14]**

## **7.1 Suitable options**

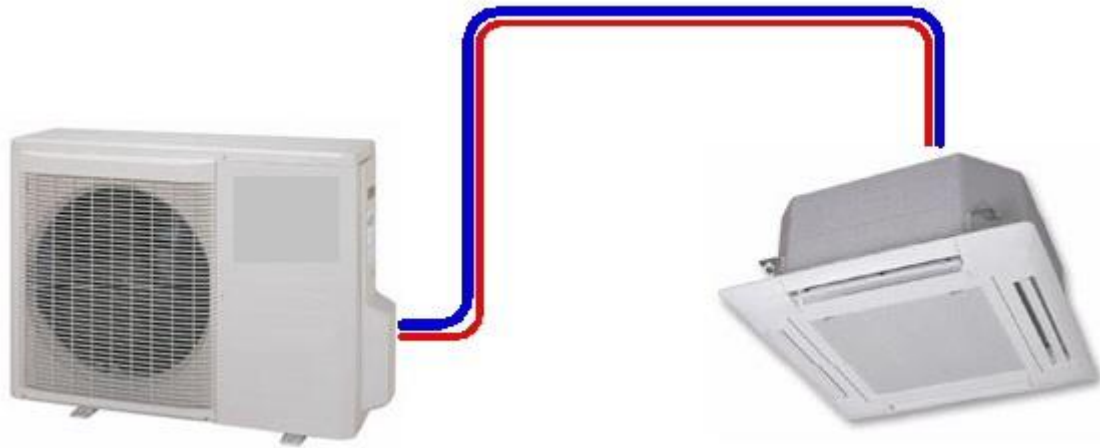
Choices of equipments were made on the basis of specifications that were of high value to Wärtsilä. Both types of equipment can be bought and installed locally in most cases, which facilitates service. Both can also be relatively cheap, considering the prices for earlier ventilation units. The reliability of these systems is also of importance.

### **7.1.1 Split-unit system**

Split-unit AC is probably the easiest to install and the most economical in smaller projects. The system will be built with two AC split-units for each E&A module, which can either be supplied by Wärtsilä or by subcontractors on site.

Two units are put into one room mainly for backup reasons in case if one of them malfunctions in some way. Another benefit is that they do not have to work at full capacity constantly.

Both units can manage a cooling capacity of 50 % of their actual workload when both are running. If one malfunctions, the other one can increase its efficiency to 80-90 % and still do the necessary cooling while the other one gets repaired or replaced.



**Figure 11. AC split-unit, possible solution**

The benefits with these units are that they are easy to install. The installation can easily be done locally, and spare-parts can be found almost everywhere. They are also controlled room-wise, which means that if the temperature varies in one room it is easy to adjust.

This can also be one of the problems, because it is difficult to make these units work as a central system. If it becomes necessary to change the cooling, it has to be done separately for each room. Another disadvantage can be that there will be very many units to maintain in larger plants.

There were some concerns regarding the placement of the outdoor unit. The best placement for it would be on the roof of the power plant, but that is also the best placement for the engines' radiators. This could lead to complications with the cooling of the engines and could have an effect on the performance. After considering this, the decision was made to contact the people in charge of the efficiency of the engine's radiators. After explaining the situation, permission was given to continue to work with the roof option. The outdoor units will have some effect on the radiators, but the heat that they distribute can be handled. Some small changes can still be made. No connections between the units will go through the roof, all will go through the wall.

The other option for the location of the outdoor unit could be on the ground, possibly at the same distance as the radiator field (approximately 30 m from the plant house). More closely situated alternatives are under consideration.

The most likely location of the outdoor split-unit is still on the roof for both the indoor and the outdoor alternatives.

### 7.1.2 Chiller system

The other alternative is a centralized chiller system. This means that a main cooling device will be placed close to the modules, and this device will cool all the rooms simultaneously. The capacity of the units will slightly exceed the needed cooling capacity. The unit can then work on a lower level and will still give the needed capacity. Then the units can easily adapt if changes in outside or inside temperatures occur for both needs. The units most suited for these needs will be from around 35 kW to 40 kW. A single unit can then cool up to 6 LV-rooms. Two or more chiller units will then be needed to supply the cooling capacity for power plants with more than six engines.

One of the demands made by Wärtsilä was that the chiller unit should have two compressors. Many models have just one. This is to get a stable redundancy in the system. The system would be more stable with two working units. The total cooling capacity of the system is divided between the two compressors. If one of them malfunctions, the other unit can still cool the rooms in the system at half of the total capacity until the other compressor is repaired.

In the chiller case, only one cassette outlet is needed per room. This is because the cassette contains a small number of moving components and the risk of a system failure is low. The cassette outlet only contains the cooling conduits' connections and a fan for distribution in the room. All the main components are placed in the main cooling unit, where the compressor is the most important part. The main unit will be placed where it will be easy to access for instant service if needed.



**Figure 12. Second solution, centralized chiller system**

The chiller system can be a better alternative in dry places, such as deserts where there is often dust in the air. It can be easier to maintain one or maybe two chiller units than a line of split-units. The operation of the chiller is then more demanding for the personnel.

## **7.2 Suitable sub-suppliers**

After going through different manufacturers and their alternatives, two were chosen for further discussions. These were one company that Wärtsilä uses as a standard sub-supplier of the split-unit alternative, and a possible, new subcontractor of the chiller system.

Wärtsilä's standard sub-supplier is a reliable company and has been used in several Power Plant projects during the years. The company has a varying range of cooling solutions and a number of them are well suited for the needed cooling capacity. An alternative that can be used is one of their cassette units. Its dimensions are 286x575x575 mm and it has an outdoor unit that manages effects of 5 kW. That leaves a good margin in the most extreme cases, where the heating effects were 4.4 kW, on the basis of calculations.

The company can also supply Wärtsilä with a chiller solution. The main unit will have an effect of 35 kW, which is more than enough for the needed capacity. It will use a cassette model called Skystar (from a different brand) and it will use almost the same dimensions, 275x575x575 mm. These units can be chosen in two sizes. The smaller one can handle the needed capacity, as it manages effects up to 5 kW.

Preliminary prices have been given for both alternatives. The split-units will be around 2500 € per unit. The price for the chiller system will then be between 10 000 and 11 000 € for the chiller unit, and around 1000 € per cassette unit.

The other possible supplier is a leading brand that manufactures different sizes of chiller systems for larger offices and industrial buildings. This company has an extensive list of good references. Their chiller units fill the needs Wärtsilä has and they have units with the needed cooling capacity. Since the company has not done any business with Wärtsilä earlier, there may be some time before prices are available. Quotations will be requested at a later stage, when more details are clear.

## 8 Conclusions

After a thorough review of different cooling solutions and suppliers, two alternatives have been chosen on the basis of this thesis. Both are well suited for Wärtsilä's specifications and the customer can choose in which option is better for his needs. One option is the split-unit ac, the other one is a centralized chiller system that can use the same spaces inside the LV-room. Their pros and cons have been checked, and both options are well suited for the needs that were calculated.

The pros are that both alternatives can use the same spaces for the indoor units, and redundancy can be guaranteed with both systems. The chiller option is then a better alternative in dry and dusty areas, where air filters often clog. It is easier to maintain one or two chiller units than a large number of split-units if filter changes have to be made on a frequent basis.

There are some cons with both alternatives. In larger power plants, there will be very many split-units to maintain if that alternative is chosen as two units are needed for every LV-room. Chiller units with the right specifications can be difficult to find locally in some areas.

Both alternatives were chosen because they can fill the needs for both outer and inner heat outputs. There were some worries about the placement of the outdoor units in the split alternative, but an approval was given and they will be placed on the most suitable location for these units. The chiller alternative will not have any problem with space needs.

Both alternatives are available in various formats on the market. The split-unit alternative is probably more easily installed and maintained locally, since it is a very widespread product today. The chiller demands more knowledge of the personnel that maintain the units. Maintaining of both alternatives is not the major issue, both are still relatively simple to operate.

Redundancy for both alternatives has been checked and actions for failings have been considered. The split-unit alternative will have two units for each room, one mainly for backup. The chiller units will have two compressors that have the combined capacity for the whole system. One compressor can still cool the system for some time at system half capacity while the other one gets replaced.

The suppliers of this new equipment have been chosen among companies that Wärtsilä finds reliable and can start collaboration with in future projects. Both suppliers have a wide range of alternatives that can be used in case new changes come in the future.

Since this is a pilot idea, it will not be tested yet for some time. Hopefully a project involving these new electrical & automation modules will be delivered within this year. After an order has been placed for these new plant solutions, some changes might be needed in the layouts and the drawings considering the AC-units, depending on which alternative the customer chooses. But hopefully the new E&A modules will work to both Wärtsilä's and the customers' satisfaction.

## 9 Discussion

This has been an interesting topic to write a thesis about. I have learned a lot and gained a thorough insight in different cooling systems and how they work. There was a lot of work at the start, with all the new cooling systems to learn and their pros and cons. All of this was new knowledge to me, and there was a number of cooling alternatives to go through before the most appealing ones were chosen for further consideration. But the workflow has since been good and the result is what we wanted. Both alternatives are well suited, both in terms of costs and cooling capacity. The help from Wärtsilä's personnel has been of great use when I wrote this thesis and I would like to thank everybody who has been involved in this thesis. The result will hopefully help Wärtsilä to get a working concept that involves these new electrical modules.

The electrical & automation modules are now almost ready for test building, some work is still needed. If these new modules prove to work properly and can actually reduce the electrical costs substantially, then these solutions can become strong competitors on the power plant market.

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# Appendices

Appendix 1: Cut-out from Excel calculation sheet for heat losses

Appendix 2: Old designs for Power Plant LV-room (cut-outs)

Appendix 3: New Designs for Power Plant LV-room

# Appendix 1

## U-coefficient:

Outer wall	=	0.44	W/m <sup>2</sup> °C
Roof	=	0.44	W/m <sup>2</sup> °C
Floor	=	0.30	W/m <sup>2</sup> °C
Window	=	0.00	W/m <sup>2</sup> °C
Door	=	1.40	W/m <sup>2</sup> °C
Floor-Ground Δt	=	15	

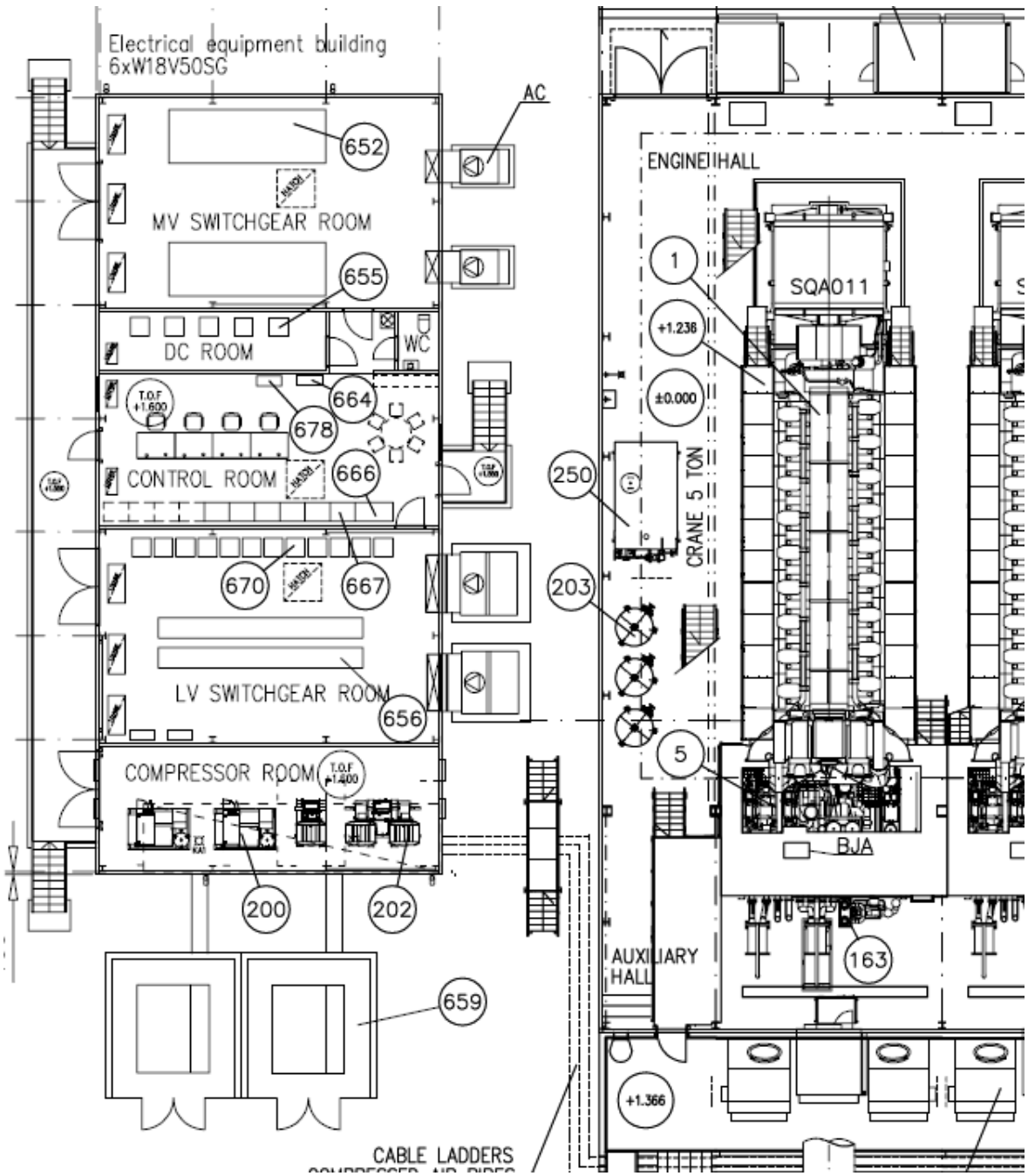
## Temperature

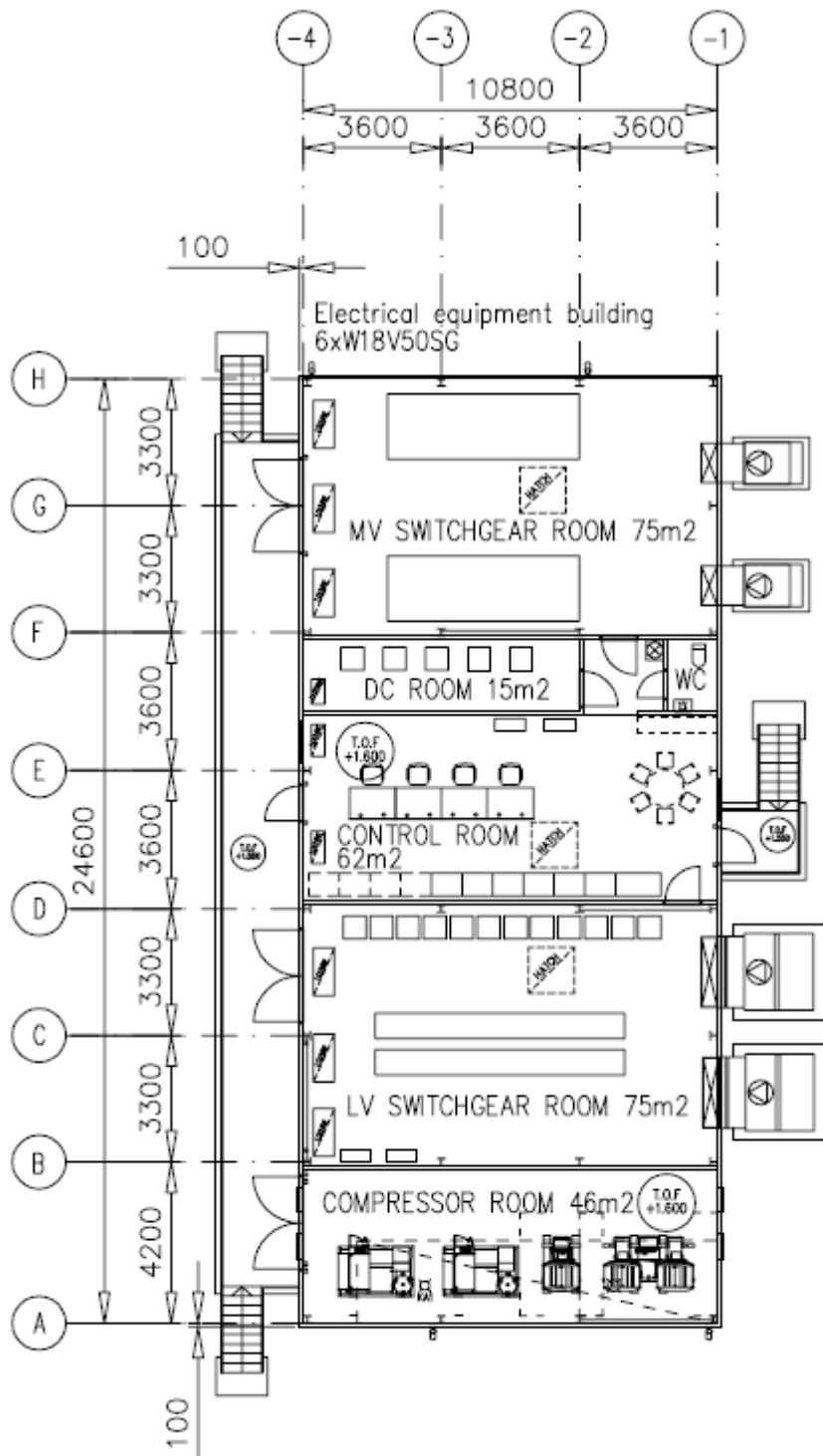
indoor =	30	°C	Leak air =	0.1	
outdoor =	70	°C		0	

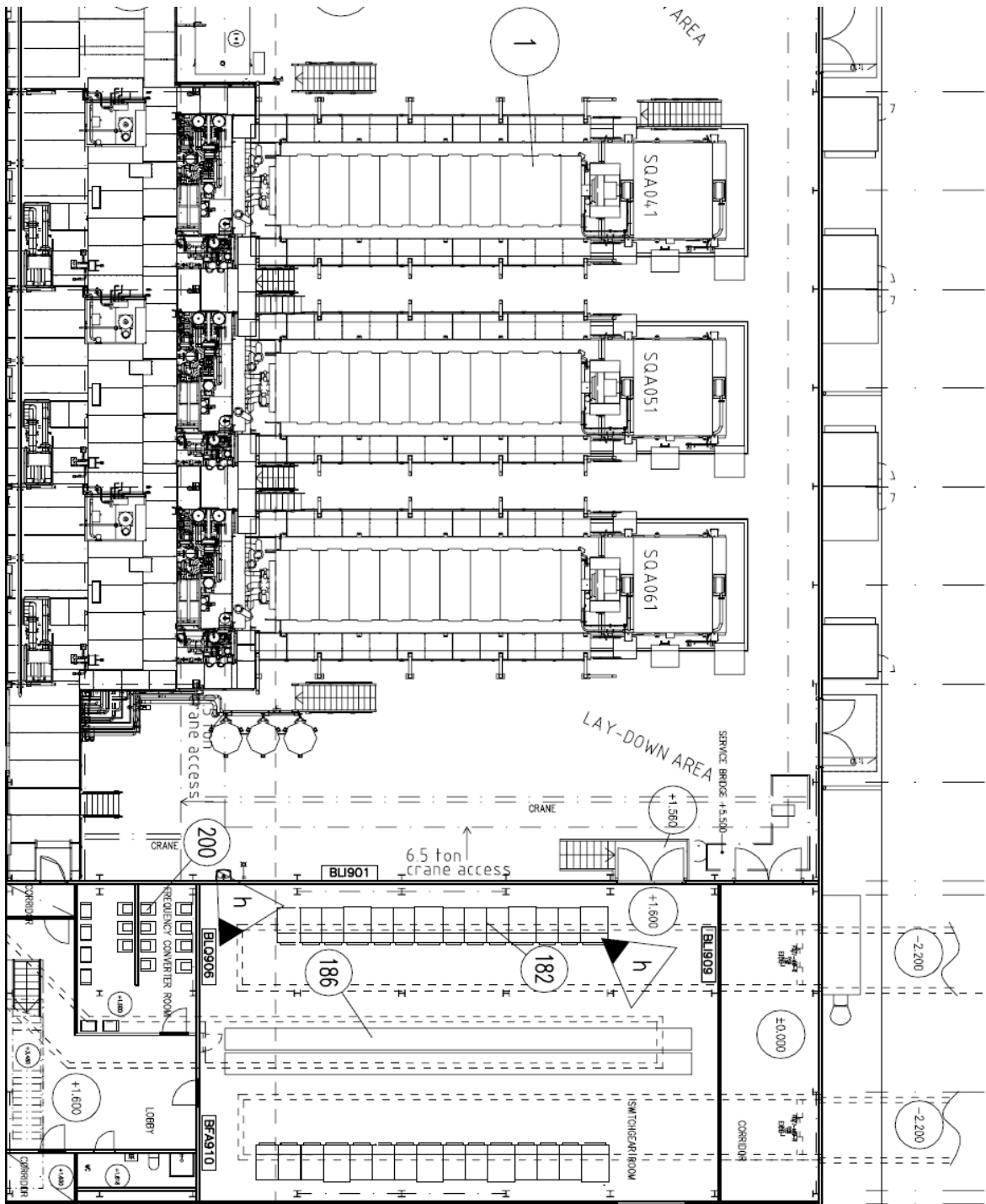
Sum heat losses =	-763.7	W
Volume	19.7	m <sup>3</sup>
Air leak losses	-26.0	W
Roof losses	-128.5	W
Roof area	29.2	m <sup>2</sup>
Outer wall losses	-513.2	W
Outer wall area	29.2	m <sup>2</sup>
Window losses	0.0	W
Window area	0.0	m <sup>2</sup>
Door losses	-128.8	W
Door area	2.3	m <sup>2</sup>
Floor losses	32.9	W
Floor area	7.3	m <sup>2</sup>

## Power house

Power house	Width x Height x (Area)	U-coefficient x (Leak)	Δt	pc	= Losses
Outer wall	= 10.8 x 2.7 x	0.44 x	-40	1	= -513.2 W
Window	= 0.0 x 0.0 x	1.40 x	-40	0	= 0.0 W
Floor	= 7.3 x 1.0 x	0.30 x	15	1	= 32.9 W
Roof	= 7.3 x 1.0 x	0.44 x	-40	1	= -128.5 W
Door	= 1.0 x 2.3 x	1.40 x	-40	1	= -128.8 W
Leak	= 7.3 x 2.7 x	0.10 x	-40	1	= -26.0 W
Sum					<u>-763.7</u>

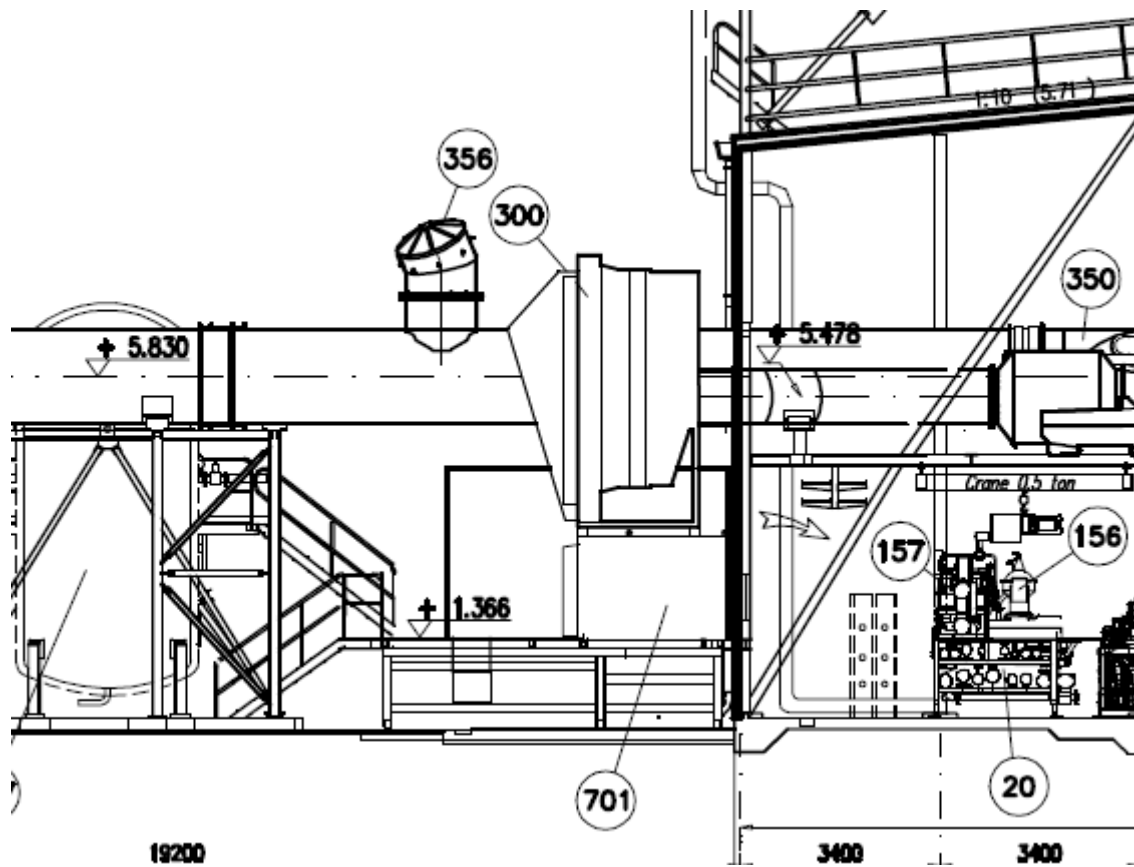


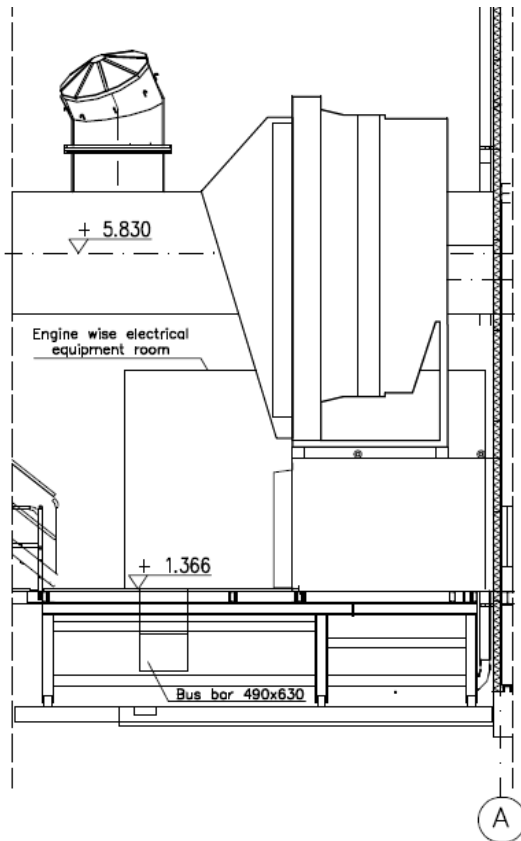




**ALTERNATIVE 1, CHANGES**

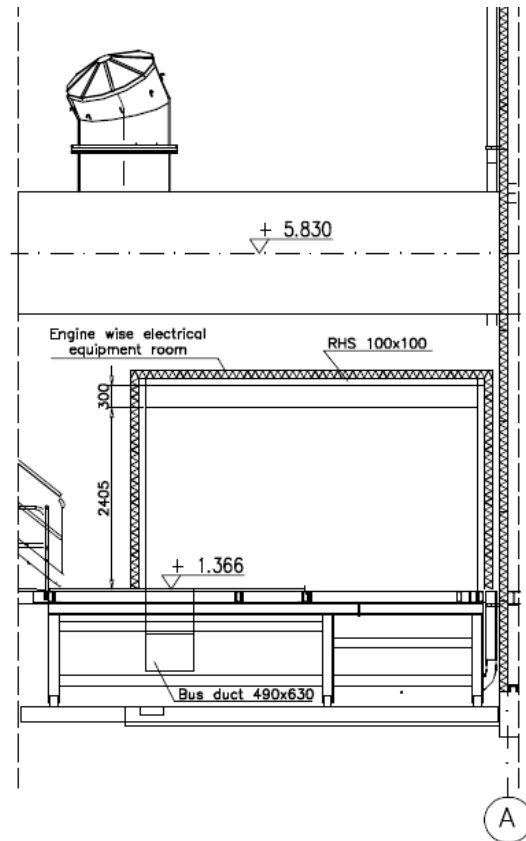
- Ventilation unit (aux. area), divided two pieces
- CA filter moved up, ventilation unit (aux. area) under it
- Stack moved 1400mm further
- Filter platform stretched ~1650mm
- 1185m<sup>2</sup> smaller site area





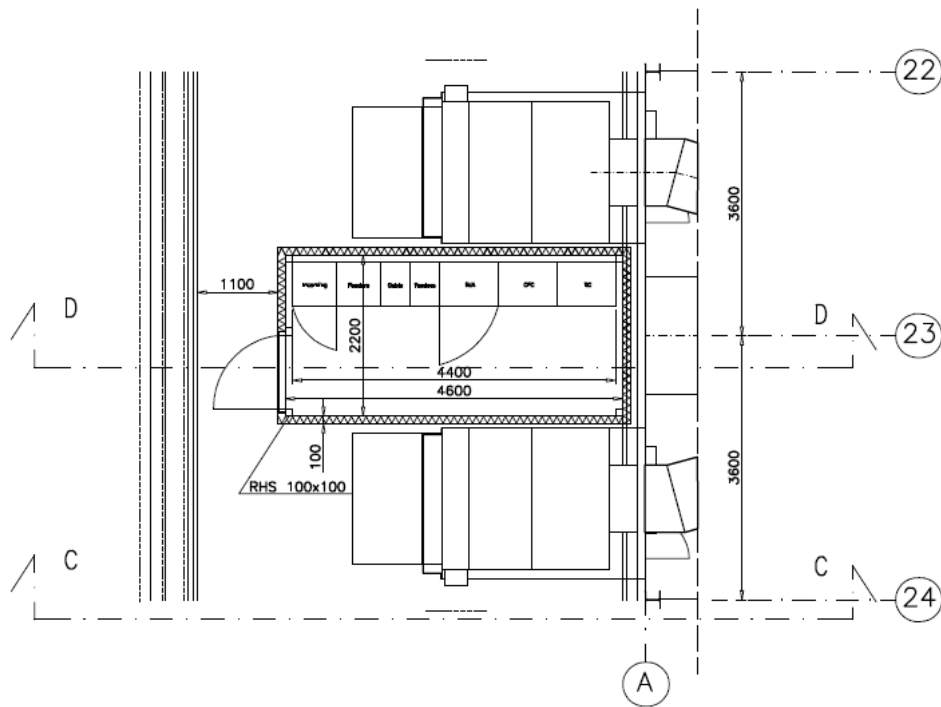
Section C-C, engine wise electrical equipment room Alt. 1

Scale 1:50



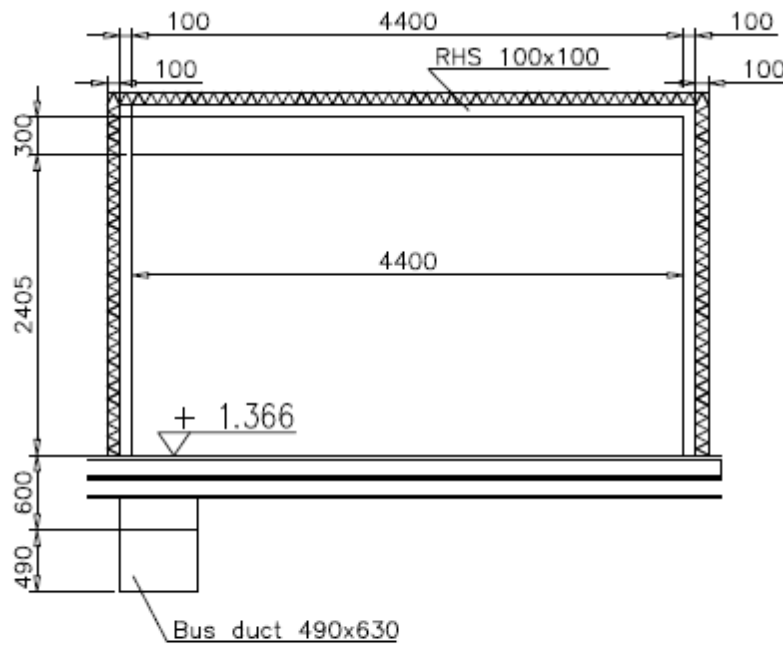
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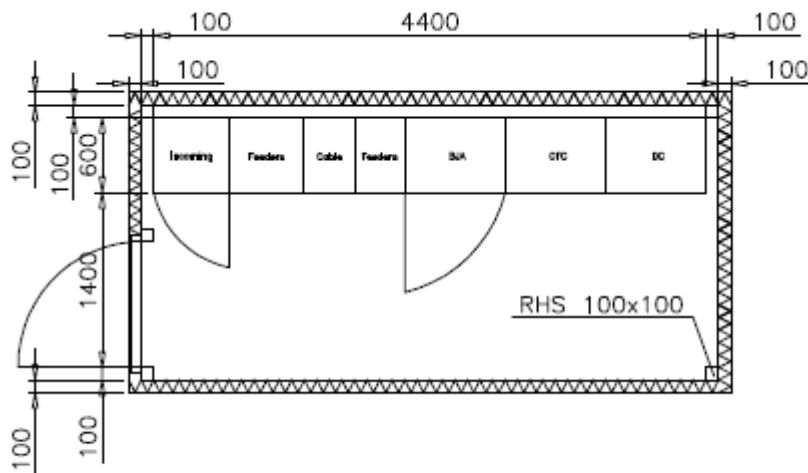
Plan view, engine wise electrical equipment room Alt. 1

Scale 1:50



Section, engine wise electrical equipment room Alt. 1

Scale 1:35

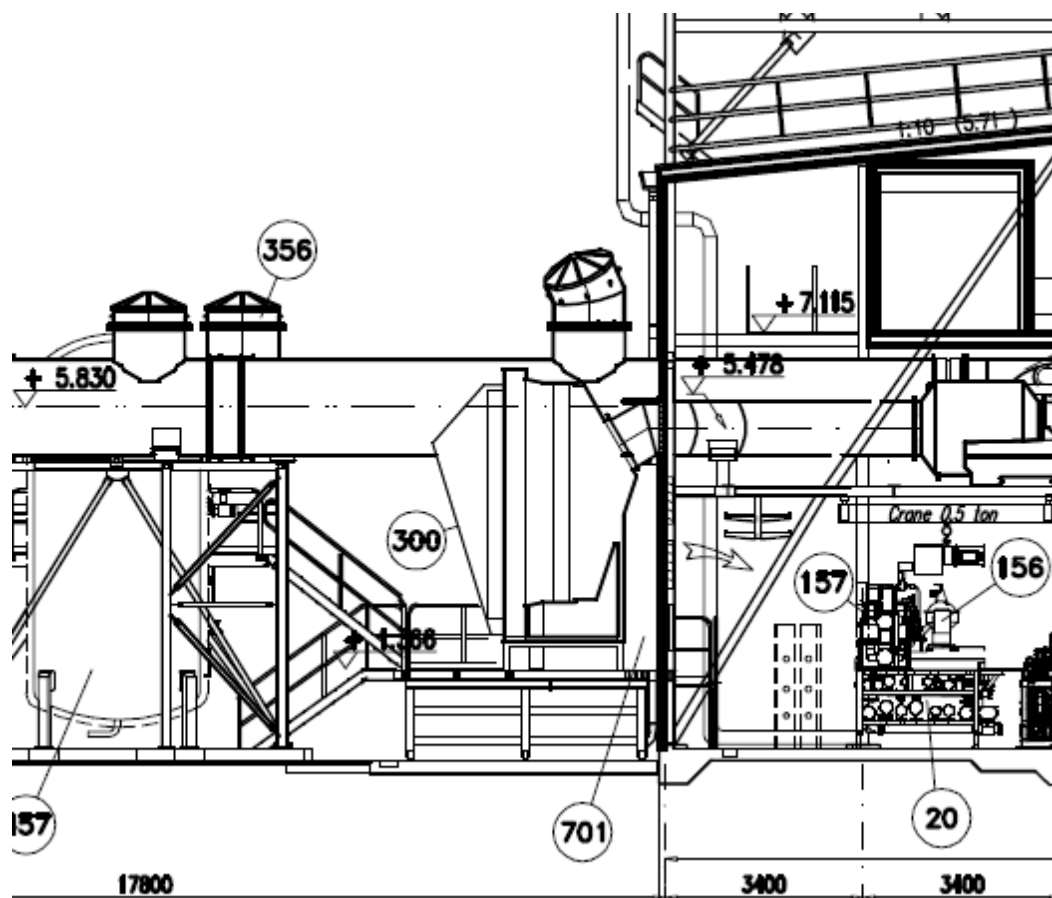


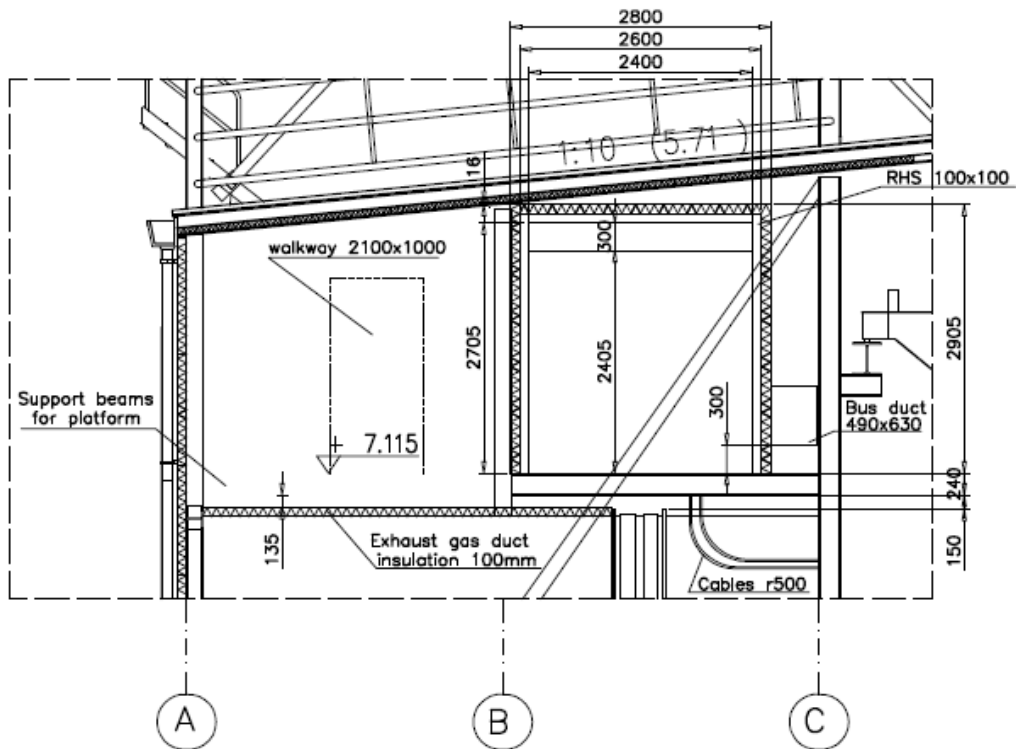
Plan view, engine wise electrical equipment room Alt. 1

Scale 1:35

**ALTERNATIVE 2, CHANGES**

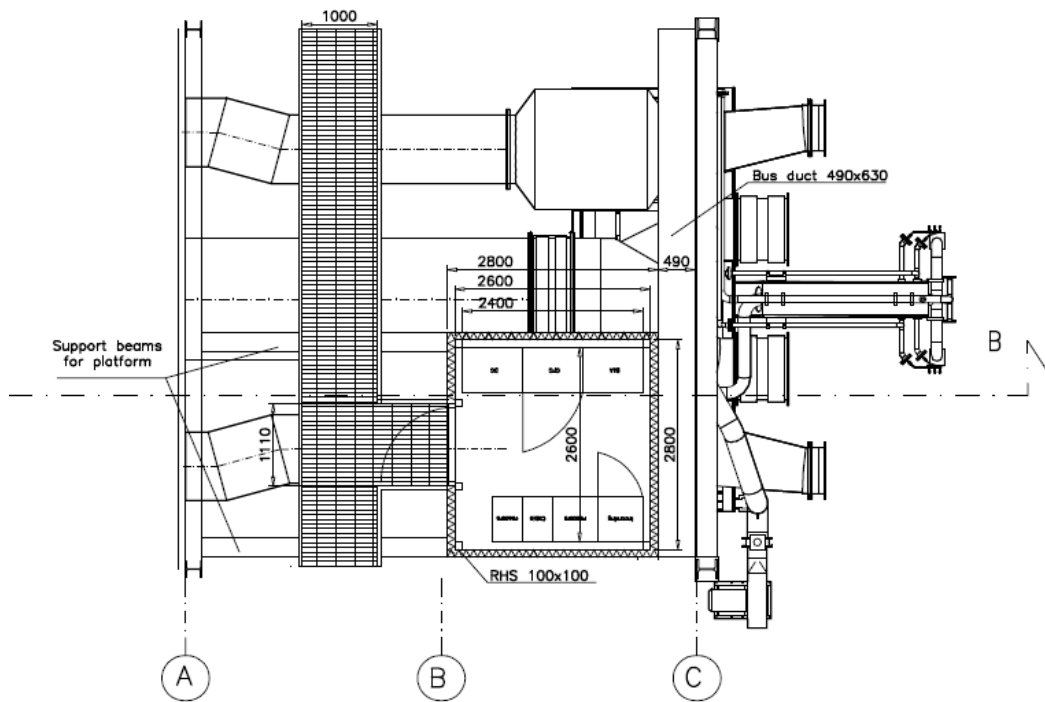
- No major changes
- Space for room is quite tight
- Platform ~7.2m/engine and ladders needed
- Support structures for room needed
- 1185m<sup>2</sup> smaller site area





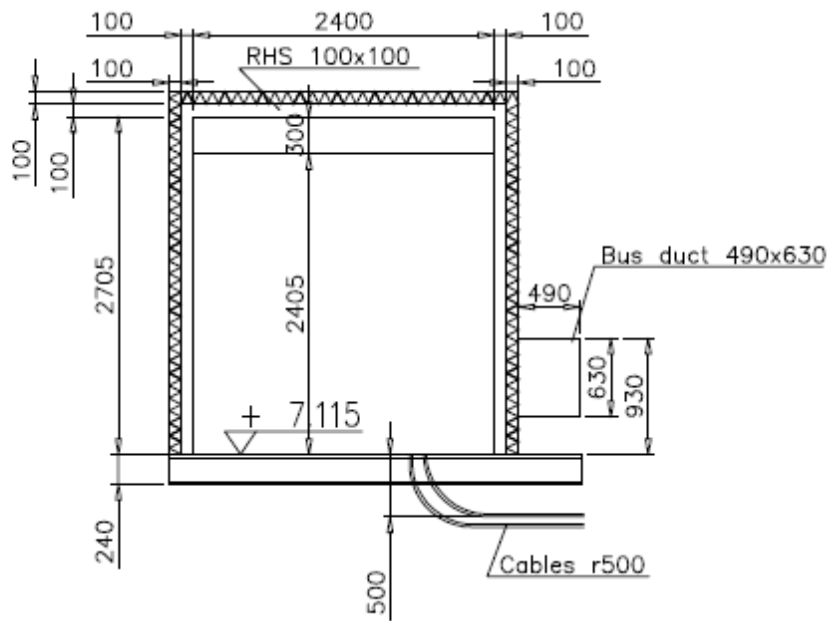
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Scale 1:50



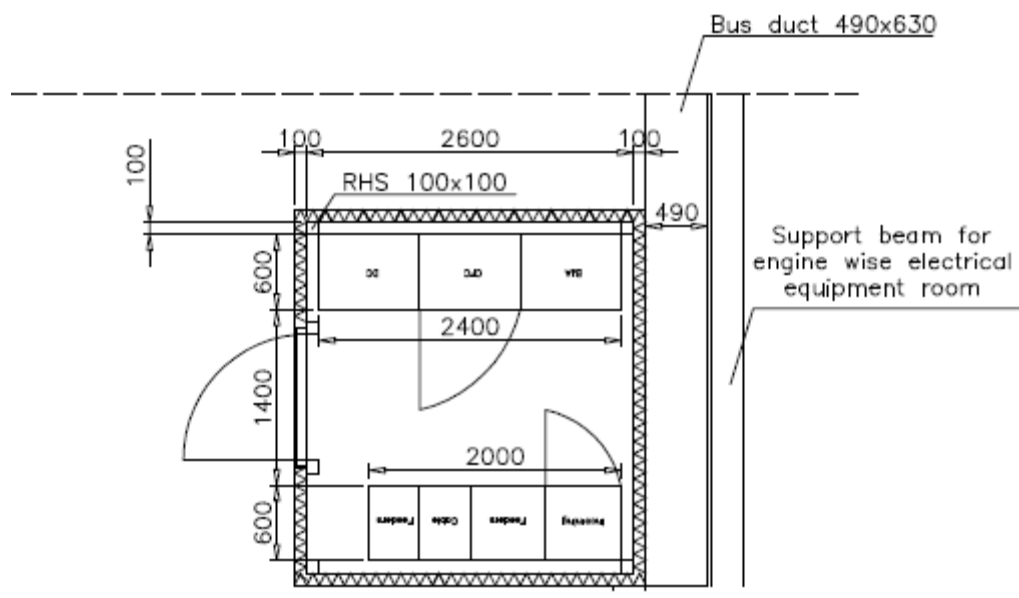
Plan view, engine wise electrical equipment room Alt. 2

Scale 1:50



Section, engine wise electrical equipment room Alt. 2

Scale 1:35



Plan view, engine wise electrical equipment room Alt. 2

Scale 1:35