



**UNIVERSITY  
OF GÄVLE**

**FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT**

**ENERGY BALANCE AND TEMPERATURE RISE STUDY IN  
CUTTING STATION AT SANDVIK AB**

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Master's Thesis in Energy System

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*Nazanin*





## **ABSTRACT**

The project is a detail study of Energy Balance in cutting line station in Sandvik Mining and construction group.

The aim of the project is reducing temperature and making a temperature balance inside the cutting line. During the recent years, many changes occur in production line. Existing cooling system cannot supply cutting area temperature below the desired level. Electrical Cables are melting due to high inside temperature. We attempted to study the old drawings and existing cooling system in cutting station to find out solutions to optimize and rebuild the old system. First part of study contains checking of preliminary air and water cooling system drawings. In the second part we looked at the operating cooling system by measuring different available working conditions such as inside temperature, air velocity and cooling water flow rate with different measuring equipment. The study integrate hot and cold stream (cooling air and water system) at different temperature level and in different times through production or non-production hours. Finally results and solutions can give valuable guidance for enterprises on how cooling systems should be expanded, what sizes should the new equipment have, where should the heat recovery exchangers be built, what new pipelines are needed, etc. To find more accurate results, we tried to do all measurements simultaneously, but due to difficult working condition it was not possible to have all input data at the same time. According to the primary data energy consumption during different times and Peak consumption amounts were calculated. Results consider the differences in cooling system effects inside the cutting line and the system which generates more cooling load and needed more improvements. The summer and winter conditions are different inside the work area. The simultaneous assurance of ventilation, energy reduction and occupant health remains a design challenge. Working area is a unman area; therefore environmental impact are not considered in this research.





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## **1. INTRODUCTION**

This chapter gives an introduction to the issues of this thesis. Firstly a background about steel industry in Sweden will be explained. In the second part there will be a brief introduction of Sandvik production plant and location of the work. In the last part specific scope of the work in the factory and aim of the project will be discussed.

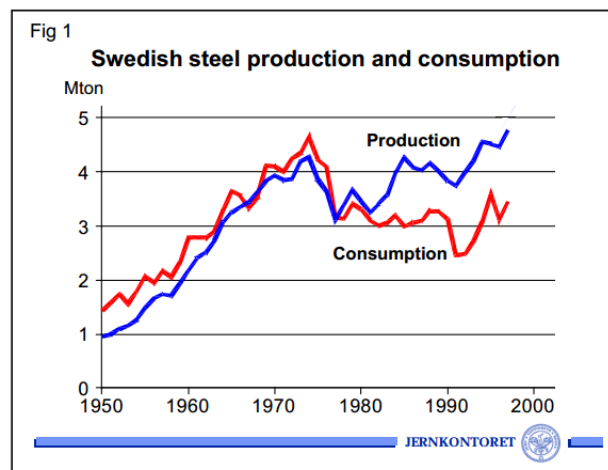
### **1.1 Sweden Steel Industry**

Sweden has been known for producing high quality steel products for many years. Abundant supply of water power for electricity production and high reservoir of pure ore with low phosphorous content convert Sweden as a producer of steel with high quality. In the beginning of 18<sup>th</sup> century, Sweden was the first iron manufacturer of the world and the supplier of about one third of the world's need. In 1980 Sweden began to export steel according to its higher amount of production than consumption (Figure.1). Average amount of finished steel consumption in Sweden is about 800 kton per qtr (Figure.2). Today Sweden has a strong international position in steel industry [1].

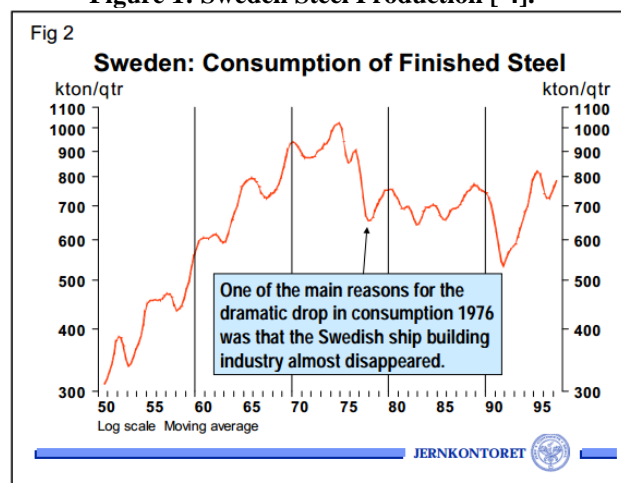
In 2008, Industrial energy use is about 38% of total Swedish energy demand. The steel industry is the second industrial energy user and consumes about 15% of total energy use in Sweden [1].

In recent years many efforts have been done to use energy more efficient in steel industry. In the steel industry energy uses for converting iron ore and scrap metal to steel. For manufacturing steel it should be heated to very high temperature and reaching to this temperature need high amount of energy. In this type of industry the cost of energy is about 15 to 20 percent of the total cost of steel production. The main sources of energy are coal or electricity generated from coal. In such integrated system very little changes in one unit influences in energy consumption of other units. An acceptable industrial system should operate to maximize the profit and minimize the energy use [2]. Heat losses are considerable and are about 13 to 36 % of total energy [3].

The steel energy industry has reduced its energy consumption since 1975. Using recycled steel also save energy for about 33 %. Nowadays about 70% of new steels are made from recycled scrap [3].



**Figure 1: Sweden Steel Production [ 4].**



**Figure 2: Consumption of Finished Steel in Sweden[4].**



## 1.2 Sandvik AB

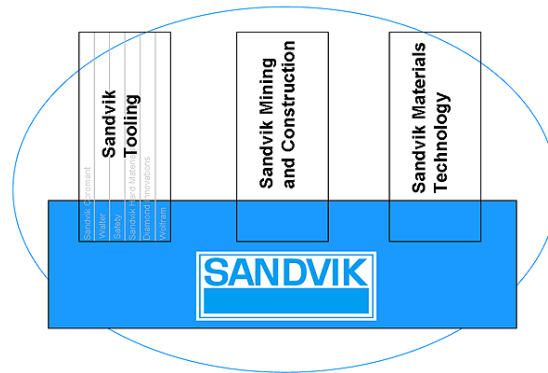


Figure 3: Sandvik Main Business Area

SANDVIK is a global engineering group and a strong brand. Sandvik production plant founded in Sandviken on 1862. It has about 47000 employees. The company consists of three world-leading business areas in a decentralized organization. The business areas have full operational responsibility and are responsible also for goals, strategies and acquisitions as well as sales, results and balance sheet for their respective unit. There are a great number of common processes and denominators between the business areas. A strong focus on materials technology, obvious R&D orientation, highly refined products, a global presence, a large internal recruitment base and the aim of working close to customers create comprehensive synergy possibilities. Coordinating financing, acquisition know-how and marketing experience are other strength factors which increase the competitive approach of the group.

SANDVIK is one cohesive group which is stronger than the aggregate value of the three business areas. [5]

### 1.3 Location

Figure4. shows City of Sandviken in Sweden map and the position of the city from Stockholm. Sandviken located in northwest of Stockholm city with 190 km distance from capital city.

Figure5. Shows main offices in Sandvik:

1. Sandvik AB
2. Sandvik Material Technology
3. Sandvik Coromant
4. Sandvik Mining and construction
5. Sandvik information Technology
6. Sandvik system Development

Cutting Line station is located near main gate at south west of the map.



Figure 4: Sandviken City

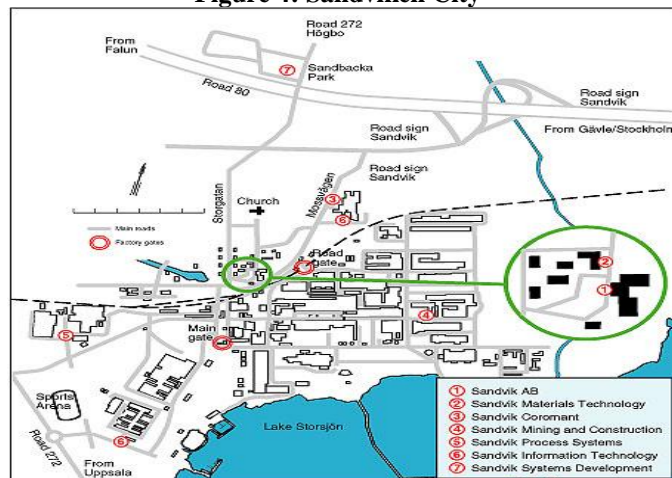


Figure 5: Sandvik AB Map

#### **1.4 Aim of the Study**

In this section the purpose of the thesis is defined. It is important to know what we are looking for and what the goals are.

The aim of the project is decreasing inside temperature of cutting line and improving the efficiency of cooling equipment. There are two main cooling systems, air cooling system and water cooling system. To find the actual cooling situation of the area we need to study both systems accurately and find the amount of heat loads generates inside the area in different production and non production hours. By making energy balance and specifying all different heat gains and heat generations the rout for controlling inside temperature will be determined.

Measurements will be done for estimating the actual working conditions and also finding out the specifications of different applied cold and hot streams in the system. Heat loads included various heat generation of hot casting material radiation and convection, and different heat losses from ventilation and cooling water. All heat generation and heat losses amounts are proportioned with variations of inside temperature. Minor changing in any cooling system can cause to high fluctuations in inside temperature and energy consumption. Calculated charts are useful guides for receiving to optimum temperature and energy amounts. By calculating total heat loads the peak amount of energy consumption will be obtained. According to the results the distinctive differences between designed system and available one will be determined.

There are two alternatives for decreasing temp and specific energy use in an industrial process:

- Practice changes inside the existing production system
- Installation of new process equipment [6].





## 1.5 Scope of Work

Type of material passing the cutting line is stainless steel that is more expensive than other type of steel, therefore appropriate cutting policy improve the utilization of the material. Once a roll is set up on the cutting line, continuously cutting without being segmented will be appeared [2].

Dimensions of casting steel passing through the line is 365 mm x 265 mm. Speed of the lines is about 0,8 m/s. Normal work duration is 135 min in Casting condition and 45 min in non-casting through a work day.

The area of study named skärstation (Cutting Station) which is located at the end of the production line (Figure 6). Cutting line included 3 main lines. Casting material temperature is about 1200° C in the beginning of the production line and when entering the cutting station material temperature will about 900° C.

In an Industrial Ventilation System both cooling and heating demands should be satisfied. The amount of energy used in casting process is proportional to the amount of metal casting [4].

Hot material immediately exiting from cutting line (Figure.7). Temperature of outgoing material was estimated in that area.

Large section of cutting station and three lines of material can be noticed. The area is divided in three main elevations (Figure.8). Supply air cooling ducts passing behind the roof in elevation about 14,00. Hot material passing in the middle parts in elevation about 1200, where cooling radiators type 1 are installed above them and Radiators type 2 are installed on the walls of middle part. Exhaust air ducts are passing through downstairs, below elevation 9.00. In the basement outgoing water passes through the main convoy.

In order to carry out this study, information about factory was given (maps, drawings, equipment specifications). This data was appropriately use for energy survey and measuring procedure. Other sources of information also be used, technician of technical services in production line, various measuring devices, other literatures, master thesis and internet based papers that can be consulted in references and appendices.

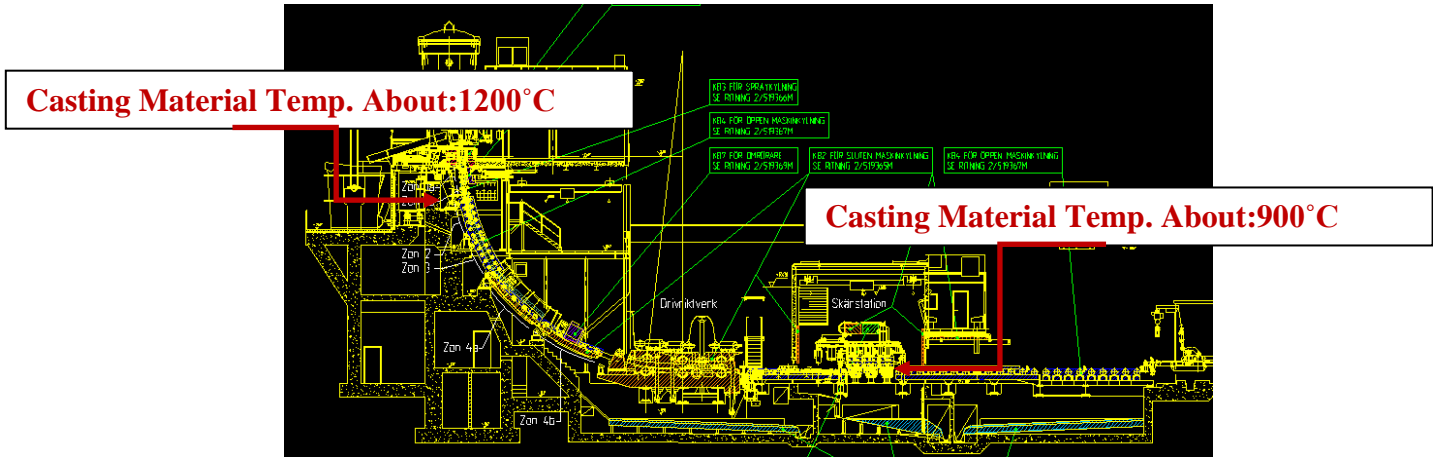


Figure 6: Main Production Section Overview

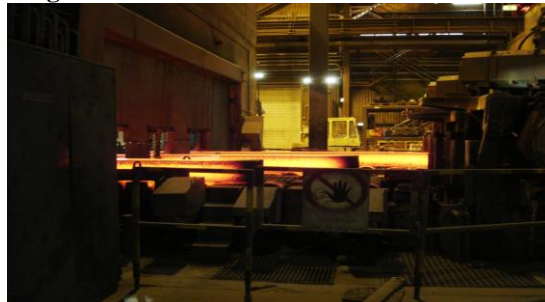


Figure 7: Casting Material Outgoing Cutting Line

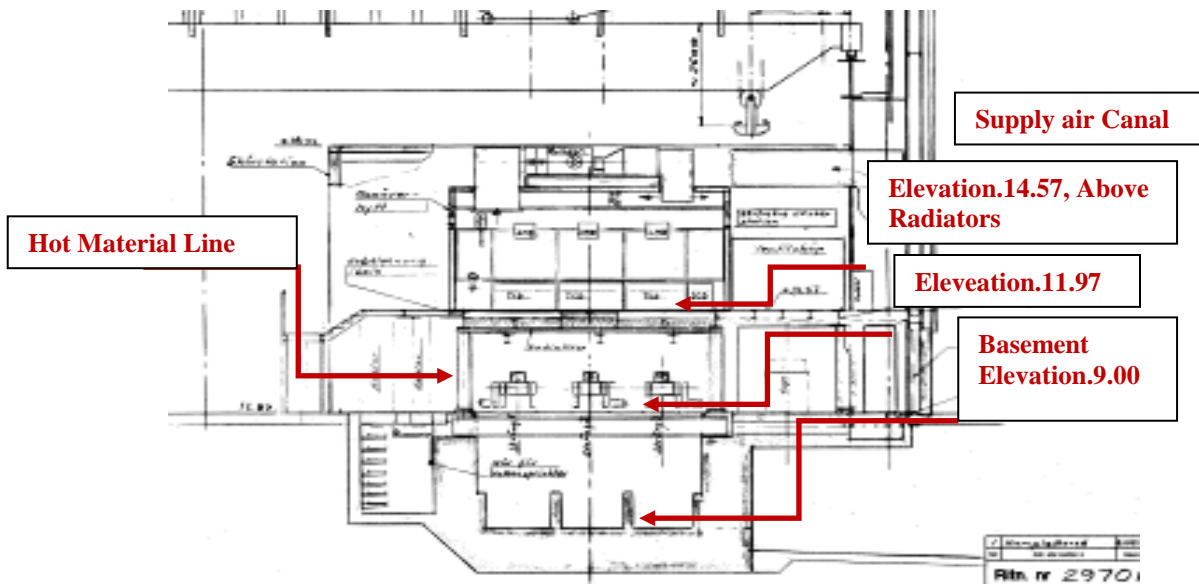


Figure 8: Cutting Line Section



## 2. THEORY

### 2.1. Industrial Energy System & Air Cooling System

Despite the availability of many innovative liquid or phase change cooling technology, forced air cooling is still the most widely used and desirable cooling techniques in many industries. The highly reliability and effectiveness makes it available in most applications and can easily manage and monitor.

Ventilation Air (Cooling Air) has two basic purposes:

- To provide an environment that permits the machinery and equipment to function properly with dependable service life.
- To provide an environment in which personnel can work comfortably and effectively [7].

According to high temperature inside the cutting line, a ventilation system is required to maintain appropriate condition and temperature inside workplace. The carried out system is normally a mixing ventilation system (MVS, figure.9). Mixing ventilation contains cold supply air from the upper part of room and warm exhaust air from the ceiling or ground level according to the building requirements. In the existence of high thermal load in high ceiling buildings, the energy expenditure will be increased to achieve a constant temperature level in the entire of the room. A vertical gradient temperature will be generated in upper part of the room get unnecessarily cooled [7].

Another alternative for mixing ventilation is displacement ventilation system (DVS,figure.10), which is installing cold air suppliers in the lower parts of walls that cause to transport warm and polluted air to the exhausted area in upper parts of the room. In the second type of ventilation system, the effective cooling consider in only lower part of the room where people work with lower energy costs.

The sizing of DVS system is an important task. Previously it was carried out by experimental methods. Engineering development and guidelines are available and many numerical methods

have been investigated through recent years. In MVS only a part of total heat losses are to be satisfied. But little performance of displacement ventilation in high ceiling rooms is characteristics in many industrial facilities [7].

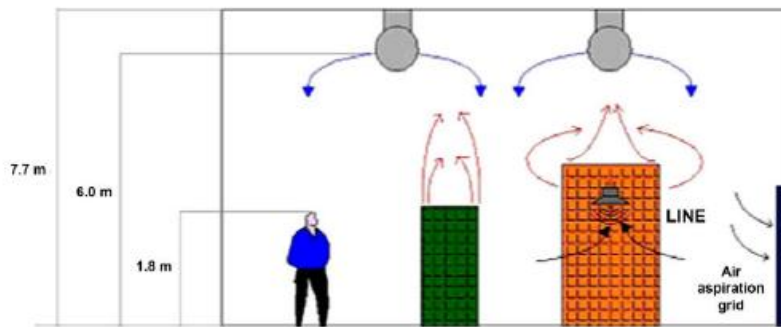


Figure 9: Scheme of Mixing Ventilation System [6].

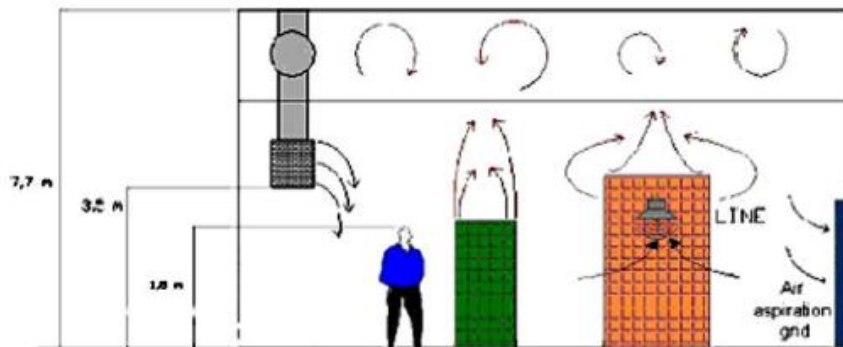


Figure 10: Scheme of Hybrid Displacement Ventilation System[6].



## **2.1.1. Various Industrial Ventilation System Definitions**

### **2.1.1.1 Design Temperature**

A properly designed ventilation system will maintain working area air temperature about 8.5 to 12.5 °C (15 to 22.5 °F) above the ambient air temperature.

Maximum temperature should not exceed 49° C (120°F). If the temperature cannot be maintained below 49° C outside air should be ducted directly to the air cleaners [8].

### **2.1.1.2 Fan Types**

The following types of ventilation fans typically used:

- Vane Axial
- Tube Axial
- Propeller
- Centrifugal

The selection of fan types is usually determines by ventilation air volume, pressure requirements and space limitation. The fans have various qualities that make them better suited to certain application [9].

### **2.1.1.3 Fan Location**

Fans are most effective when they withdraw ventilation air from the room and exhaust the hot air to the atmosphere. However, ideal ventilation system will utilize both supply and exhaust fans. This will allow the system designer the maximum amount of control over ventilation air distribution [9].

### **2.1.1.4 Fan Sizing**

Fan sizing involves much more than just selecting a fan that will deliver the airflow volume needed. It requires a basic understanding of fan performance characteristics and ventilation system design parameters.



Similar to a centrifugal pump, a fan operates along a specific fan curves that relates a fans volume flow rate ( $\text{m}^3/\text{min}$ ) and pressure rise ( $\text{mm. H}_2\text{O}$  or  $\text{in. H}_2\text{O}$ ). Therefore fan selections not only requires that the volume flow rate be known, but also that the ventilation distribution system be known in order to estimate the system pressure rise. This information allows the optimum fan to be selected from a set of manufactures fan curves or tables [9].

#### **2.1.1.5 Exhaust System**

Ventilation air exhaust systems should be designed to maintain a slight positive or negative pressure in working area.

Positive pressure should normally not exceed 0.5 Kpa or (0.2 in  $\text{H}_2\text{O}$ ). This positive pressure provides the following advantages:

- It prevents the ingress of dust and dirt, which is especially beneficial for this application.
- It creates an out draft to expel heat and odor from the working area.

Excess exhaust ventilation provides the following advantages:

- It compensates for the thermal expansion of incoming air.
- It creates an in draft to confine heat and odor to the engine room [9].

#### **2.1.1.6 Two Speed Fan Motor**

Operation in extreme cold weather may require reducing ventilation airflow to avoid uncomfortably cold working condition in the working area. This can easily done by providing ventilation fans with two speed (100 %, 50% or 67% speeds) motors [9].

#### **2.1.1.7 Routing Consideration**

General Routing Principles:

Maintaining recommended air temp in the working area is impossible without proper routing of the ventilation air. The following principles should be considered when designing an engine room ventilation system.

- Fresh air inlets should be located as far from the sources of heat as practical as low as possible.



- Ventilation air inlets and outlets should be positioned to prevent exhaust air from being drain into the ventilation inlets (recirculation).
- Ventilation air inlet and outlet should be positioned to prevent pockets of stagnant or recirculating air.
- Where possible, individual exhaust suction points should be located directly above the primary heat sources. This will remove heat before it has a chance to mix the working area air and raise the average temperature. It must be noted that this practice will also require that ventilation supply air be properly distributed around the primary heat sources [9].

#### **2.1.1.8 Duct Insulation**

In new construction projects, ducts should be insulated in accordance with energy code requirements, ASHRAE standard 90.1. In chapter 26 of ASHRAE handbook of fundamental, more information about insulation can be found.

#### **2.1.1.9 Different Types of Streams**

- A hot stream is a material stream with a specified flow and heating capacity that requires cooling-down in order to its temperature to be changed from a supply (also called source, start or initial) to a target (also called delivery or final) value. A hot stream implies a cooling demand [10].
- A cold stream is a material stream with a specified flow and heating capacity that requires heat in order to its temperature to be changed from the supply to target value. A cold stream implies a heating demand [10].

The heat of a hot stream can be transferred to one or several cold stream and heating demand of cold streams can be satisfied by one or several hot streams [10].



## **2.2. Water Cooling System**

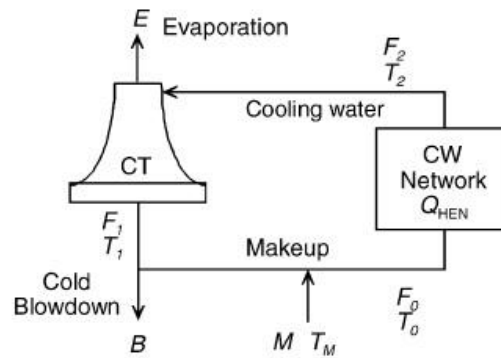
In a steel industry main water use is for cleaning and cooling. Average fresh water consumption for per ton steel was merely 3 - 4,2 m<sup>3</sup>/t in developed country in 2008. A typical cooling water system should obtain the cooling demand sufficiently without any large impact on the plant's economy or environment. Water used in process steps pump back to the river, with higher degrees. For a plant which supply district heating nearly zero-cost excess is available in summer time [11].

All types of coolers including once through cooling water system and recirculating cooling water system are used for rejection of waste heat to the environment. Recirculating cooling water are most common system which can conserve fresh water and reduce the thermal pollution of water in accordance with once through cooling system. According to the existence of many interactions between the cooling water networks and heat exchangers performance all of the cooling system components should be considered in designing and operating of the system. In many situations it is not often clear how a cooling water network affects the cooling system in new conditions. For investigating the interactions in overall cooling systems a combined water and energy analysis should be used. Pinch analysis is one of the most common designing tools which have been developed for designing heat exchanger networks through the last decades [12].

### **2.2.1. Cooling water system model**

The cooling water system consists of the cooling tower, recirculation system and heat exchanger network (figure 11). The hot return cooling water from heat exchanger cooled in cooling water. The minimum cooling water demand is determined by minimizing the flow rate to the individual heat exchangers. Studies on cooling water system models demonstrate that the cooling water temperature is affected by changing in the water inlet conditions. When water enters with low flow rate and high temperature cooling water will obtain water with lower outlet temperature. Higher temperature increases the corrosion potential in cooling system. Corrosion rate double for every 10°C rise in temperature. When cooling water treatment is important in the system, temperature limit for return water will be considered. In retrofit the temperature difference could be chosen to comply with the performance limitation of an existing heat exchanger under revised operating conditions of reduced temperature differences and increased flow rate. Also the

limiting cooling water profile might be determined by other process such as corrosion, fouling, cooling water treatment, etc. [12].



**Figure 11: Cooling Water System.**

For district heating /cooling system (hot/cool water) delivered amount of energy will be calculated as follows [23]:

$$E = m' \cdot c_p \cdot \Delta T \cdot \tau = q \cdot \rho \cdot c_p \cdot \Delta T \cdot \tau$$

## 2.3 Heat Transfer Formulations

### 2.3.1 Ventilation Air Flow Heat Transfer

Required ventilation air flow depends on the desired area temperature [13].

$$V = \left( \frac{H}{D \times Cp \times \Delta T} \right) \times F$$

**V = Ventilating Air (m<sup>3</sup>/min)**

**H = Heat Radiation i.e. engine, generator, aux (kW)**

**D = Density of Air at air temperature 38°C. The density is equal to 1.099 kg/m<sup>3</sup>**

**CP = Specific Heat of Air (0.017 kW x min/kg x °C)**

**ΔT = Permissible temperature rise in engine room (°C)**

**F = Routing factor based on the ventilation type**

The rate of energy consumption due to this sensible heating or cooling is given by [13]:

$$q_s = Q\rho C_p \Delta T = 1200Q\Delta T$$

Where

*qs = sensible heat load, W*

*Q = airflow rate, m<sup>3</sup>/s*

*ρ = air density, kg/m<sup>3</sup> (about 1.2)*

*cp = specific heat of air, J/(kg·K) (about 1000)*

*Δt = temperature difference between indoors and outdoors, K*

### 2.3.2 Cooling Water Heat Transfer

The rate of heat transfer to or from the water is a function of the flow rate, specific heat, and temperature rise or drop of the water as it passes through the heat exchanger. Energy consumption calculation for both systems is similar. The heat transfer to or from water is expressed by: [13]

$$q = m'_w (c_p)_w (T_o - T_i)$$

$m'_w$  = Mass flow rate of water (kg/s)

$(c_p)_w$  = Specific heat of water = 4,18 kJ/kg<sup>o</sup>k

$T_o$  = Temperature of water out, °C

$T_i$  = Temperature of water in, °C

### 2.3.3. Radiation Heat

Radiated heat from the materials and other machinery in the working area is absorbed by equipment surface. Some of the heat is transferred to the atmosphere. The remaining radiated heat must be carried away by ventilation system [14].

The amount of thermal radiation depends on the following factors:

- Temperature of both emitting surface and receiver
- Emitting of the radiating surface
- Reflectance, transmittance and absorptance of the receiver
- View factor between the emitting surface and receiver surface

### 2.3.4. Thermal Radiation

The wavelength of the most of the infrared, all of the visible light and a part of the ultraviolet spectrum is a range referred to as *thermal radiation*, since it is this part of the electromagnetic spectrum that primarily creates a heating effect. When a substance thermal energy increases (temperature), the electromagnetic radiation produced by this temperature increase is primarily in

the thermal radiation band. A portion of the shorter wavelengths in this range is visible to the human eyes [14].

### 2.3.5 Heat Transfer by Thermal Radiation

#### MRT Method

In this Method the thermal radiation interchange in an indoor space is modeled by assuming that the surface radiate to a fictitious, finite surface that has an emitting and surface temperature that gives about the same heat flux as the real multi surface case (Walton 1890). In addition, angle factors do not need to be determined in evaluating a two surface enclosure. [14]

$$q_r = \sigma \cdot F_r [T_p^4 - T_r^4]$$

Where

$Q$  = net heat flux because of thermal radiation on active panel surface,  $W/m^2$

$\sigma$  = Stefan-Boltzmann constant =  $5,67 \times 10^{-8} W/(m^2 \cdot K^4)$

$F_r$  = radiation exchange factor (dimensionless)

$T_p$  = effective temperature of heating (cooling) panel surface,  $^{\circ}C$

$T_r$  = temperature of the fictitious surface (unheated or uncooled),  $^{\circ}C$

The temperature of fictitious surface is given by an area emittance weighted average of all surfaces other than the panels:

$$T_r = \frac{\sum_{j=p}^n A_j \epsilon_j T_j}{\sum_{j=p}^n A_j \epsilon_j}$$

Where

$A_j$  = area of surfaces other than panels,  $m^2$

$\epsilon_j$  = thermal emittance of the surfaces other than panels

The radiation interchange factor for two surface radiation heat exchange is given by the Hottel equation:

$$F_r = \frac{1}{\frac{1}{F_{p-r}} + \left(\frac{1}{\varepsilon_p} - 1\right) + \frac{A_p}{A_r} \left(\frac{1}{\varepsilon_r} - 1\right)}$$

Where

$F_{p-r}$  = radiation angle factor from panel to fictitious surface (1.0 for flat panel)

$A_p$ ,  $A_r$  = area of panel surface and fictitious surface, respectively

$\varepsilon_p$ ,  $\varepsilon_r$  = thermal emittance of panel surface and fictitious surface, respectively (dimensionless)

Different emittance surfaces in the room:

1. Concrete walls and ceiling
2. Radiators
3. Ducting System
4. Cutting Equipment

**Type of panel surface: Stainless Steel 316L, 900 °C**

Thermal emissivity:

Rough Concrete:  $\epsilon_r = 0.9$

Polished Stainless steel, 435°C,  $\epsilon_p = 0.45$

$A_p = 2 \times 6 \times (0.265 + 0.365) = 7,56 \text{ m}^2$

Approximate area of walls & Ceiling,  $A_r = 250 \text{ m}^2$

$Fr = 0.815$

### 2.3.6. Heat Transfer by Natural Convection

Natural Convection occurs between heating panel surface and indoor air. Thermal coefficient in natural convection is not easily calculated. In natural convection temperature difference in boundary layer of the heating surface generates air motion. Many factors in the indoor area affects on natural convection. Mechanical ventilation, occupants' movements and infiltration are some functions that disturb natural convection. The effect of forced convection should be added to the natural convection coefficient. Natural convection heat flux in a panel system is the function of the effective panel surface temperature and the temperature of the air layer directly contacting the panel. [14]

**1. Natural Convection heat flux between an all heated ceiling surface and indoor air:**

$$q_c = 0,20 \frac{(t_p - t_a)^{1,25}}{D_e^{0,25}}$$

**2. Natural convection heat flux between a heated floor or cooled ceiling surface and indoor air:**

$$q_c = 2,42 \frac{|t_p - t_a|^{0,31} (t_p - t_a)}{D_e^{0,08}}$$

**3. Natural convection heat flux between a heated or cooled wall panel surface and indoor air:**

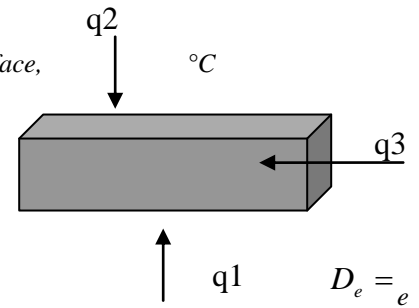
$$q_c = 1,87 \frac{|t_p - t_a|^{0,32} (t_p - t_a)}{H^{0,05}}$$

Where

$q_c$  = heat flux from natural convection,  $W/m^2$

$t_p$  = effective temperature of temperature controlled panel surface,

$t_a$  = indoor space dry bulb air temperature,  $^{\circ}C$



equivalent diameter of panel ( $4 \times \text{area/perimeter}$ ),  $m$

$H$  = height of wall panel



### **3. METHOD**

In this section, it will be explained what the thesis is based on. In the other words, it will be given details of the chosen path for achieving the aim of the thesis. As it is important to know where to go ahead in the project, it is important to know which is going to be the path. Methods contain three main parts, in the first part different types of measurements (Velocity measurement, IR Termography) and related equipment will be discussed. In the next part measurement uncertainty and different definitions and methods for obtaining uncertainty and more accurate results will be found. The last part contains the procedure of calculating and making energy balance in the area of study.

#### **3.1. Measurement Techniques**

A number of techniques are used to measure the velocity and flow rate of an air mass. These measurement techniques include plate orifices, nozzle, venturi tubes, pitot tubes, vane anemometers. For accurate measurement of both air velocity and temperature we accomplish measurements in several areas. The incorporation of different sensors to measure the air temperature, barometric pressure and relative humidity can further increase the accuracy of the velocity and flow measurement. The volumetric flow calculates by measuring the average velocity of a stream passing through passage of the known diameter. The placement of measuring device in a passage will influence how accurately the measured flow tracks the actual flow through the passage. Calibrating the measurement system can farther increase the accuracy of the velocity and the flow measurement [15].

A common way for balancing and control of HVAC systems (air or water) is adjusting valves and other devices in order to obtain the desired distribution of the air or water flow rates [16].

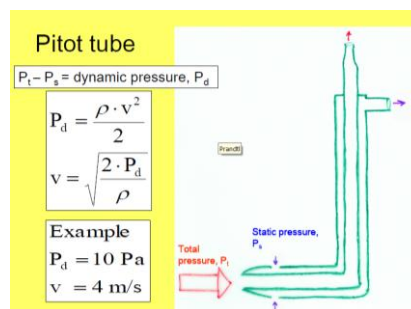
Different types of velocity flow meters:

- Pitot Tubes
- Thermal

- Ultra Sonic
- Turbine
- Magnetic

**Main Methods of Measurements of air flow rates in ventilation system:**

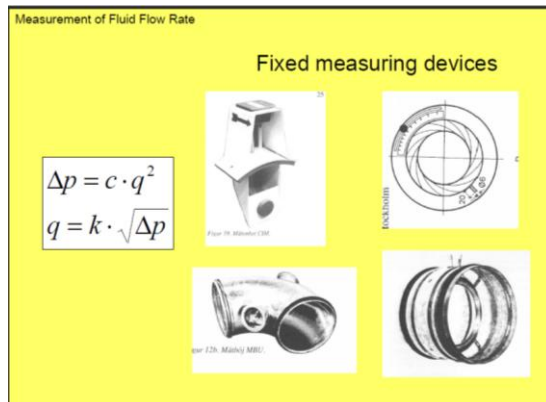
1. Air flow Measurements in ducts:
  - Traversing with Pitot tube
  - Fixed measuring devices
  - Tracer Gas
2. Extract Air Devices
3. Supply Air Devices



**Figure 12 : Pitote Tube**

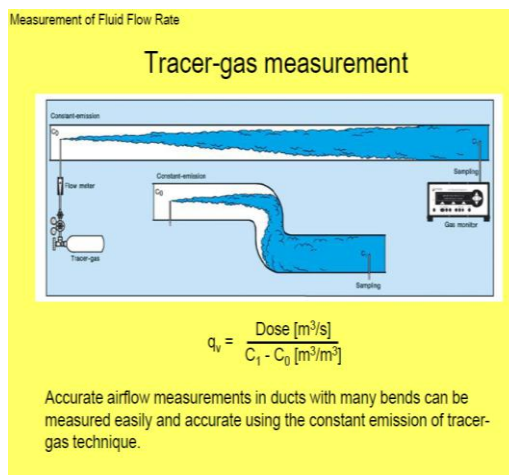
**Advantages of fixed measurement devices:**

- Fast Measurement
- Accurate Methods
- Continuous Measurement Possible
- Inexpensive Methods



**Figure 13 : Fixed Measurement Devices**

In tracer gas measurements accurate air flow measurements in ducts with many bends can be measured easily and accurate using the constant emission of tracer gas techniques.



**Figure 14 : Tracer Gas Measurement**

### **Types of Extract Air Devices:**

- Measurement on Extract Air Grilles using thermal anemometer ( the 4 point method)
- Measuring pressure drop with probe
- Measuring on fixed pressure tap
- Measurement with anemometer with hood

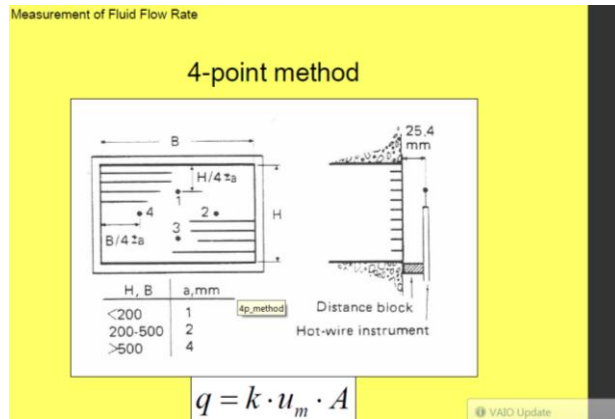


Figure 15 : 4 Point Measurement

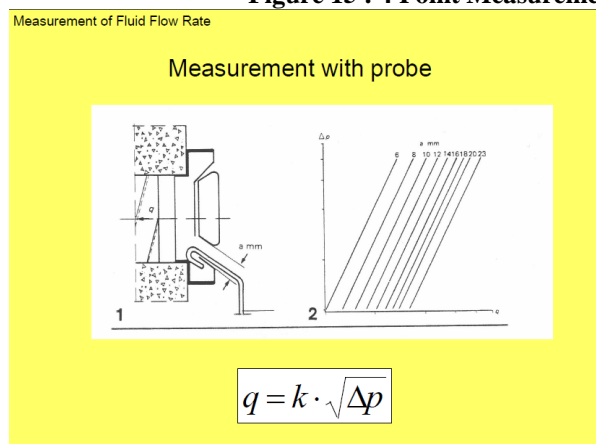


Figure 16 : Measurement with Probe

**Supply Air Devices:**

- Measuring on fixed pressure tap
- The Bag Method

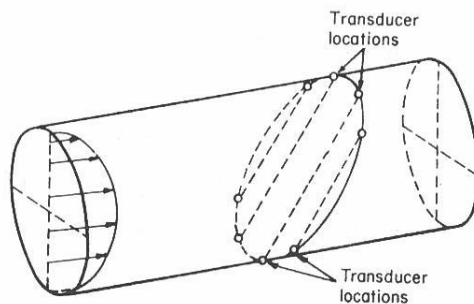


Figure 17 : Arrangement of Transducer in Ultrasonic Flow meter

### **3.2 IR Thermography**

Infrared radiation, visible light and ultraviolet lights are all forms of energy in the electromagnetic spectrum. The only difference is their wavelength frequency. Infrared radiation can also be called infrared energy or heat energy. It is light with a wavelength that not possible to detected with human eyes. It is a part of the electromagnetic spectra detected as heat. All objects with a temperature above absolute zero ( $-273\text{ }^{\circ}\text{C}$ ) emit heat and infrared radiation. Even very cold objects, like ice, emit infrared radiation. The higher the objects temperature, the greater the IR radiation emitted with shorter wavelength. By inventing IR techniques we are able to see objects which our eyes are not able to see. The techniques which use infrared camera are called Infrared Thermography ITG. The infrared energy converted into electronic signals which create a thermal image and perform temperature calculations. Information about infrared camera will be found in appendix II.

Infra red camera allows an industrial environment to monitor thermal performance and identify the heat related problems. Usually finding a problem with an infrared camera is not enough. An accurate temperature measurement is obligatory. To determine a specific temperature rise, measurements of operating temperature in different periods besides infrared reading at the same time should be considered [17].

### 3.3 Calibration and Measurement Uncertainty

There is always general overconfidence in the accuracy of measurement results and adequate calibration is needed. In fact a measured value is not very worthy without consideration of some uncertainty. In most cases when uncertainty of measurement value or instrument specification stated notation of  $\pm$  should accompanied with the information. Instrument calibration yields measuring value closer to the true value. Measurement uncertainty is an estimate of the range within which the true value is believed to be.

***Error = Measured Value – True Value***

***Corrected Value = Measured Value + Correction***

There are some over confidence in the accuracy of measuring instruments, especially when they show a lot of digital digits. It is very important to analyze uncertainty in measurement although it is very time consuming. Correction obtained from instruments calibration certificates. Sometimes calibration also means that the instrument is adjusted such that its output comes to closer to the true value. Recalibration is needed almost every year. Properties of instruments gradually change through times and affect the final output. Measured values might be changed with time and space.

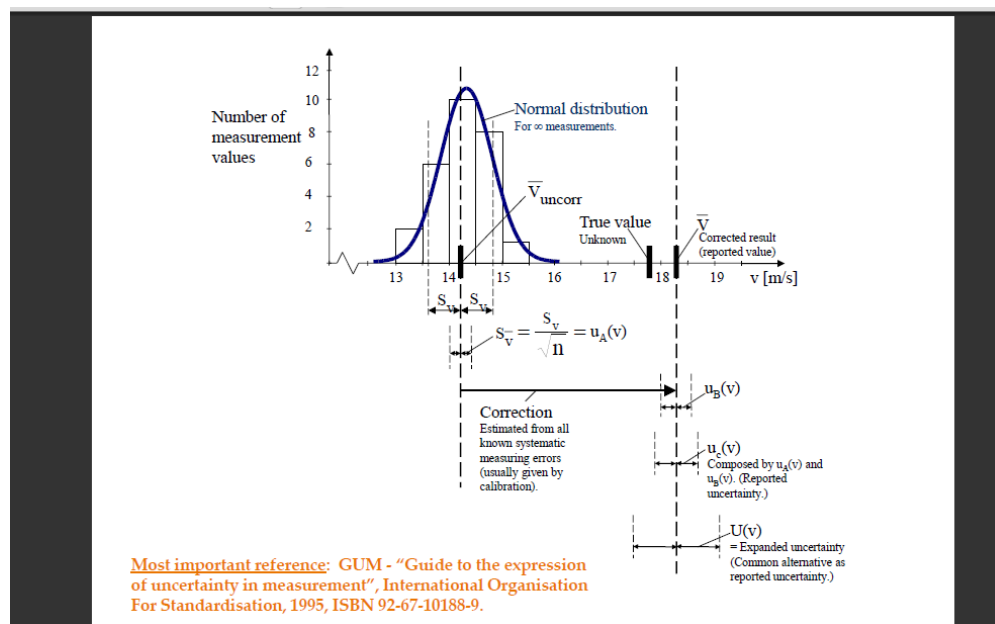
The calibration of a measurement instrument results should be added to the measured values to get to the true value. When the correction is given in absolute form, has the same unit as measured value. Related correction given in a percentage of the measured value. Correction factor should be multiplied with measured value.

In 1995 international standard of measurement uncertainty introduced; Guide to the expression of uncertainty in measurement GUM. The standard is accepted by most countries. The uncertainties are so called "errors". There are two common errors, *random errors* and *systematic errors*. *GUM* distinguishes Type A uncertainties (evaluated by statistical methods and associated with random errors) and Type B uncertainties (evaluated by non-statistical methods and often not always associated with systematic errors). The combination of two types of uncertainties gets our measurements to a total uncertainty of measurement.

The basic method of estimating uncertainty according to GUM will be discussed through following example. We start measuring air velocity for the ventilation duct. We repeat the measurement 16 times,  $n=16$  with a small time differences between every measurements. There will be some variations in the measured values. Velocity fluctuates because of uncontrollable changes in the environment (e.g. temperature changes and mechanical vibrations) which affect on the instrument and measured quantity. All of these variations call random errors. The histogram in the figure.18 shows the measured value of our examples.

Type A standard uncertainties are always evaluated by statistical methods and will be reduced by increasing the number of measurement. The reduction factor is  $1/\sqrt{n}$ . Type B standard uncertainties are attained from instrument specification or calibration report and from other different experienced-based input.

Estimated combined uncertainty united both types of uncertainty. An old fashion method is root-sum-square.  $U_c$  is smaller in that method than simple addition method. [16].



**Figure 18 : Distribution of Measured Values**

- $\bar{V}_{uncorr}$  = The uncorrected mean of the measurements (sample mean)
- $S_v$  = Standard deviation of the measurements (sample standard deviation)
- $S_{\bar{v}}$  = Standard deviation of the mean (=standard error)
- $n$ =Number of measurements

$u_A(v)$  = Type A standard uncertainty (Exist due to random errors in time or measurement position. Evaluated by purely statistical methods applied to the measuring data.)

$u_B(v)$  = Type B standards uncertainty (exists mainly due to uncertainty in the correction for systematic error. Not evaluated by statistical methods but instead from instrument specification, calibration reports, previous similar measuring data and/or other experience based input.)

$u_c(v)$  = Combined standard uncertainty of the measurement. GUM recommends:  $u_c = \sqrt{u_A^2 + u_B^2}$

$U(v)$  = Expanded uncertainty for the measurement ( $\pm U$  = "confidence intervals"). GUM recommends  $U = 2 \cdot u_c$ , giving level of confidence ~ 95%. It is then 95% probability that the true value lies within  $v \pm U$ .

### Uncertainty in Instrument Reading:

For a **digital instrument** with interval  $\Delta x$  in the last digit, the standard uncertainty is:

$$u = \frac{\Delta x}{\sqrt{12}}$$

For a **Pointer Instrument** with the interval  $\Delta x$  between smallest scale divisions used in reading, the standard uncertainty is:

$$u = \frac{\Delta x}{6}$$

### **3.4 Heat Balance**

The aim of an energy balance in a system is providing a general view of the unit and processes and energy use inside it. It is possible by comparing of energy consumption of each process. When the amount of energy used of each process is specified, energy balance can be done. Energy balance calculation indicates the most high consumption process and the one that used less amount of energy. The measurements will be focused to make a comparison between old and new systems. In an ideal system heat gains must be equal to heat losses.

The first step in doing a heat balance is determining all the ways that heat enters (heat gains) and leaves (heat losses) in the building. For detail calculation of energy balance we need all input and output temperature and air flow. Measurements have been done for specifying needed amounts.

The ideal cooling process means removing the heat load from indoor to outdoor using the minimum amount of energy. Since the flow rate of air or water is restricted in actual system, there should be temperature difference between supply and return water or air in order to carry cooling capacity. And since the heat transfer coefficient and heat exchange area are limited in actual system, there should be temperature difference between water and air, or water and refrigerant in order to transfer heat between two fluids.

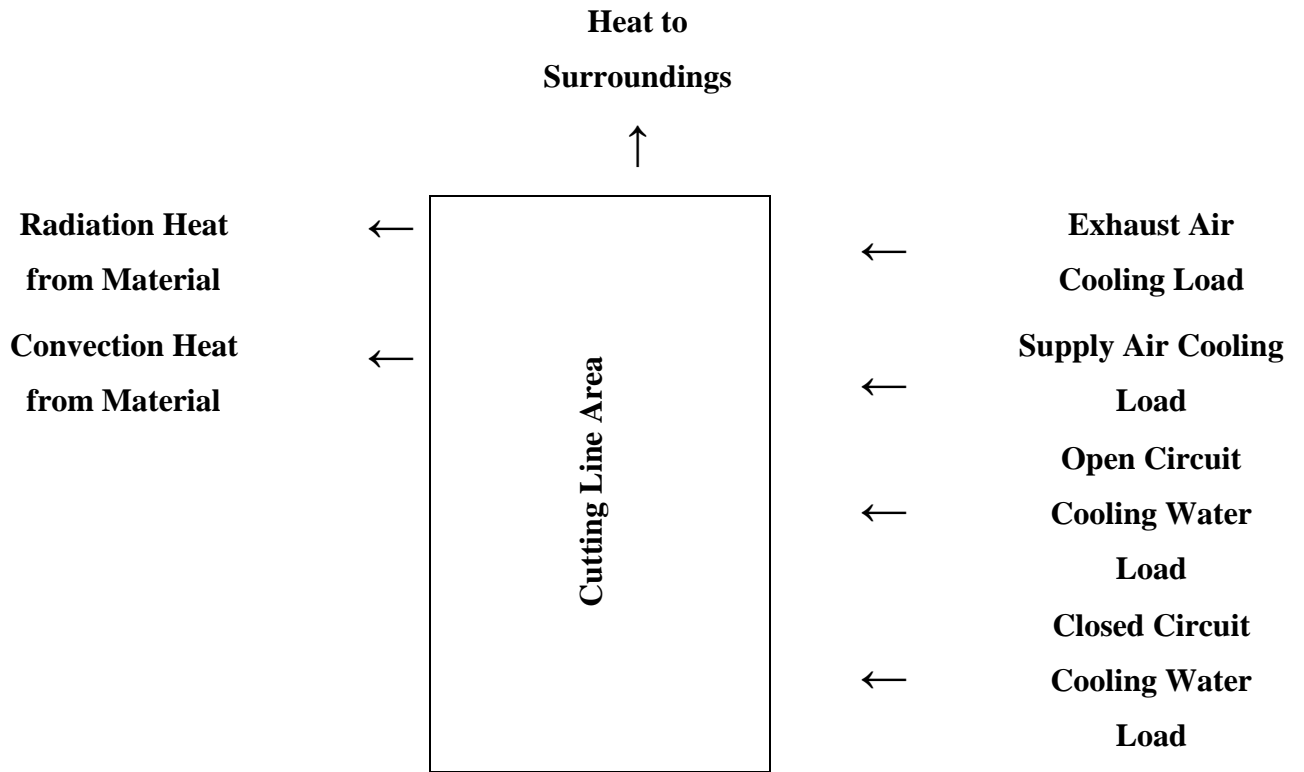


Figure 19 : Heat Balance schematic Diagram inside Cutting Line

$$\textit{Total Heat Generation} = \textit{Material Radiation} + \textit{Material Convection} - \textit{Open circuit cooling Water} - \textit{Closed Circuit Cooling Water} - \textit{Supply air Load} - \textit{Exhaust Air Load}$$

### 3. PROCESS AND RESULTS

#### 3.1. Air Cooling System Description of Installation

Main part of air cooling system is a radial fan type NBA 125 which was produced previously by BAHCO Company. According to the company new productions catalogue, company doesn't produce ventilation fan today. Supply fan uses outside air as fresh air in summer and inside air at winter. Supply air ducts passing in elevation below 14.00 and Return diffusers located in elevation about 9.00. Detail Specification of the supply fan can be found in Appendix V. The rout of connecting to the main fan is shown in the below figure. Supply air canal passing below the ceiling. The exhaust duct in the basement previously connected to the nearest outside filter. At the moment it is connected to a large filter house via a long distance ducting system. The air is very dusty for entering to the outside air. Therefore it should pass through filters before entering to outside air.

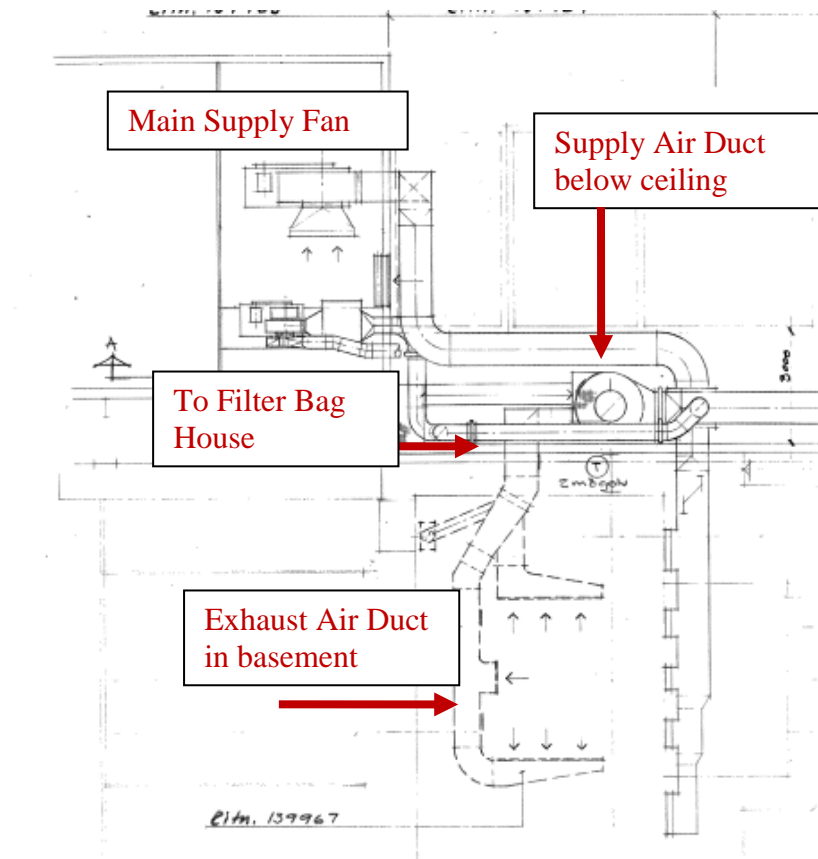


Figure 20 : Ducting System Plan DWG.

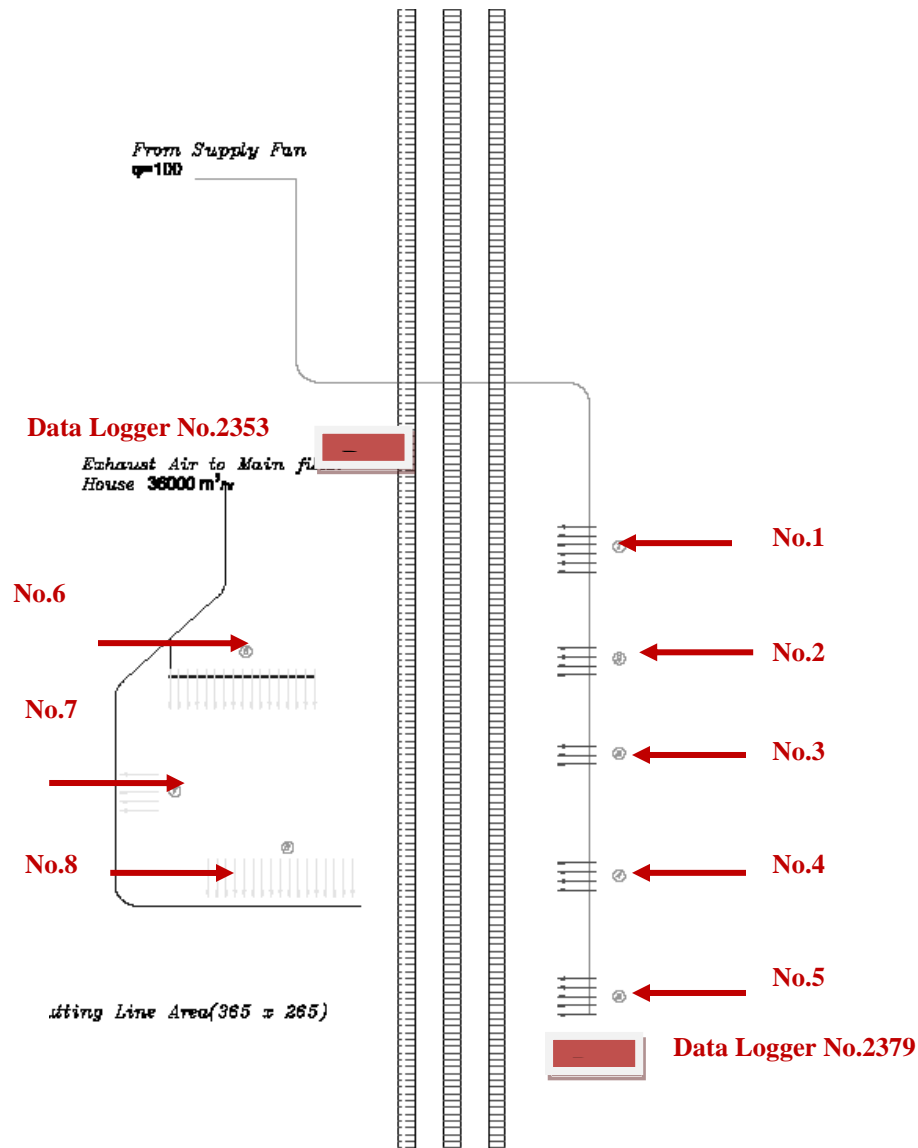


Figure 21: Air Flow Diagram inside Cutting Line

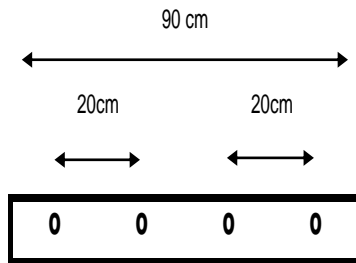
For measuring temperature and humidity inside the cutting line, we installed 4 data loggers in different areas (Two in fan room and two inside the cutting line) during January of 2012. The data loggers measured temperature and humidity every 15 minutes. In figure.21 positions of data loggers and air branch numbers in cutting are specified. In fan room a data logger is installed at inlet of fan damper and another one is installed besides wall damper in same time.

No.	Branch	Size(mm x mm)	Area (m <sup>2</sup> )	Flow Rate(m <sup>3</sup> /hr)	V(m/S)
1	Supply	1250 x 300	0,375	10000	10
2	Supply	850 x 300	0,275	9000	10
3	Supply	700 x 300	0,21	6400	10
4	Supply	700 x 300	0,21	6400	10
5	Supply	850 x 300	0,255	8500	10
6	Return	3000 x 400	0,96	18000	8
7	Return	3000 x 400	0,3	7000	8

**Table 1: Design Flow Rates Table for Supply and Exhaust Diffusers**

Different branches are numbered in flow diagram, Figure.21 are inserted in table1. The size and air flow rates of different branches are calculated according to standard velocity for industrial ventilation system. There are some differences between actual sizes of diffusers and the mentioned dimensions in the drawings, in table 1 you can find the real dimensions of installed diffusers in the working area. The velocity of supply diffusers assumed as 10 m/s and return grilles as 8 m/s. By comparing the given data on drawings with the measurement results of ventilation system it will permit to see if the calculations and assumption are close from the true. According to the above amounts total exhaust air is near to the 36000 m<sup>3</sup>/hr that we assumed before. The sum of Supply flow rates is about 30000 m<sup>3</sup>/hr which seems reasonable according to the fan operations curves.

There are many problems during measuring procedure. The main problem is measuring though working conditions and also the time of measuring (if it is production or not).



**Figure 22: Dimension of Holes in Exhaust Air Canal**

For measuring exhaust Air flow velocity and Temperature we made 4 holes on the main exhaust canal. Return air width is about 900 mm. The holes bore are about 10 mm that we can send the measuring device (Veloci Calc) inside the duct and measure velocity and temperature in 4 points (Figure 22).

$$\text{Flow rate} = \text{Duct area} \cdot \text{Mean Velocity} = \frac{\Pi D^2}{4} \cdot v$$

Results can give an idea of how different unit process work. In some cases assumption had to be taken to get an approximation to the real value.



**Position of data logger near Wall Damper**



**Figure 23: Wall Damper inside Fan Room**

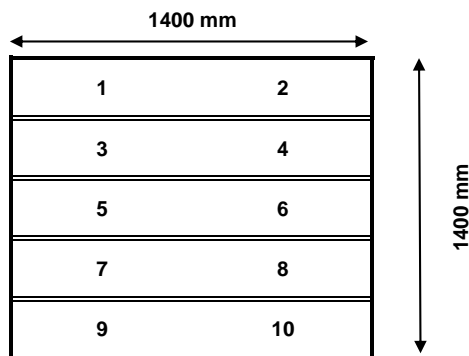
Figure.23 Shows the wall damper inside of the Fan room. The louver located between the wall of fan room and factory indoor area. The louver is open through cold months and air of indoor area entering into fan room. In summer the other louver located on outside wall will open and enter outdoor air into the fan room.



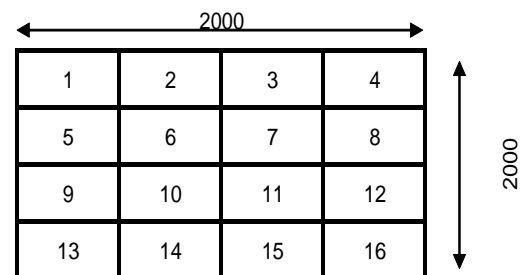
**Position of data logger on inlet damper.**

**Figure 21: Fan Inlet Damper**

To find out entering air condition another data logger installed on fan inlet damper. By studying the condition of inlet air the possibility of installing economizer dampers can be discussed. More description about results of this study will be found in the following part.



**Figure 22 : Wall Damper Dimensions**



**Figure 23 : Fan Inlet Damper Dimensions**

Figure.23 show wall inlet damper dimension. Wall damper's area is about 1400 x 1400 mm and divided 10 areas are predicted for measurement. Figure.24 shows fan inlet damper dimensions. Fan inlet damper' dimension is about 2000 x 2000 mm and divided into 16 areas. According to find more accurate amounts, measurements have been done on 16 points of fan inlet damper and 10 points on wall damper. Based on information in calculating uncertainty the reduction factor in the measurements will be 0.25 and  $1/\sqrt{10}$ . On Appendix VII detail measurement data for specific date can be observed.



### 3.2 Water Cooling System Installation

We need to consider two water cooling systems in our calculations. Both types of different cooling water system are considered in the area cooling system

1. Closed Circuit Cooling Water system(KB2, Water flowing to the radiators) as recalculating cooling water system
2. Open Circuit cooling water system (KB4, Water Sprinkling on molten material surface and outgoing through the Canal water below the working area) as once through cooling water system



**Figure 27: Cooling Water Radiators inside Cutting Line**

Figure 25 show closed circuit cooling water radiators installed on wall. There are two different type are radiators inside cutting line. Two 80 NB diameter pipes are supplying inlet water for radiators on wall and above cutting line separately. The temperature differences between inlet and outlet temperature of radiators are about 3 °C which is very low according to the assumption amounts.

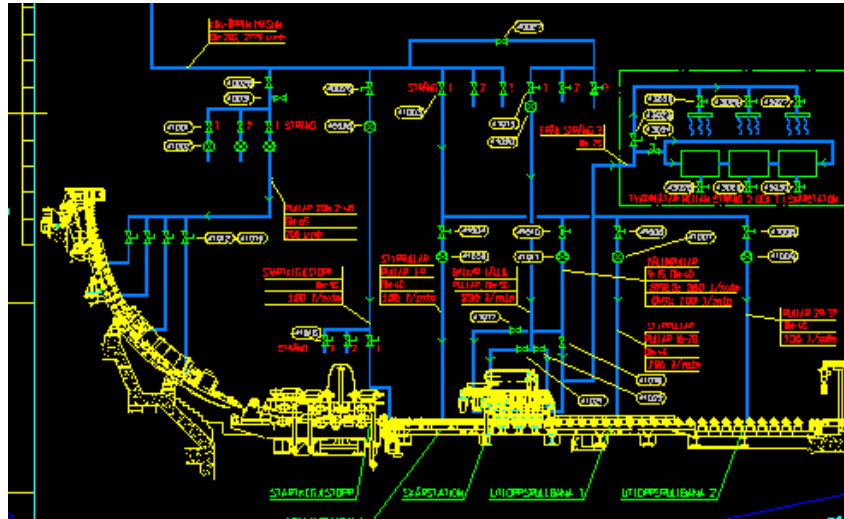
#### **Radiators Specification:**

**Type 1:** Radiators on Walls

Dimensions: 3 x 2000 x 850 mm

**Type 2:** Radiators on Top of cutting line

Dimensions: 3 x 1150 x 850 x 300 mm



**Figure 24 : Open Circuit Cooling Water Diagram KB4**

Figure.26 shows flow diagram for open cooling water system. This type of cooling system including nozzles which spray water on the surface of hot material and the mass flow rate will be poured into the water canal in the basement of working area. The temperature of inlet water is about 12° C and temperature of water outgoing through the canal is about 28 °C.

In open circuit cooling water two different connections which supply and spray water on the surface of material.

1. Rolls connections
2. Beam connections

Diameter of beams connections are 40 NB and the diameter of Rolls connections are 50 NB. Measurement amount of total flow rates passing Beams connections is 4.27 l/s and 7.68 for Rolls Connection.

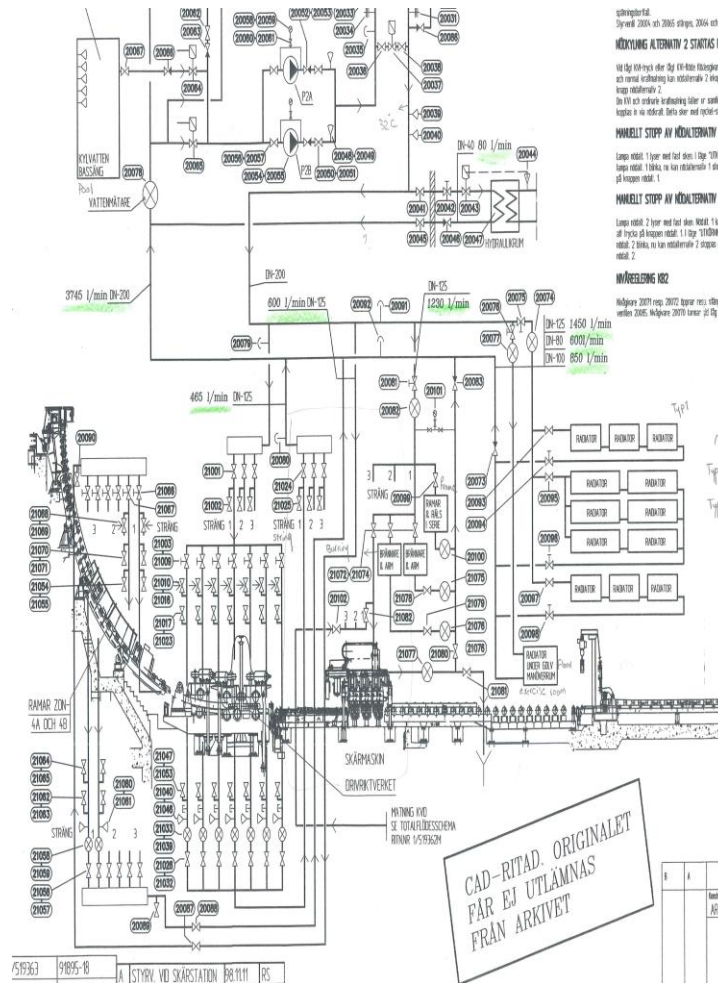


Figure 25 : Closed Circuit Cooling Water Diagram, KB2.

Flow diagram shows 9 numbers of radiators, two different types; while there are only 3 radiators on the walls and 3 radiators on top of casting flow that is one of the main reasons of flow rate decreasing inside the pipes.

According to this low amount of flow inside the pipes many errors occurs during measurement procedure, the measuring equipment is so sensible when the pipes don't contain full flow.

Water flow inside the pipes is measured with Ultra sonic Flow Meter (EUROSONIC 2000 HH) and the water temperature is measured by Laser Sighted Non-Contact Temperature Probe CMSS2000. More information about measuring devices is found in Appendix II and III. In closed circuit cooling water system heat exchanger which maintains this amount of cooling water

is plate type heat exchanger model M15-BFG8 Alfa Laval. More heat exchanger specification will be found on Appendix IV.



**Figure 30 : KB2 Heat Exchanger**

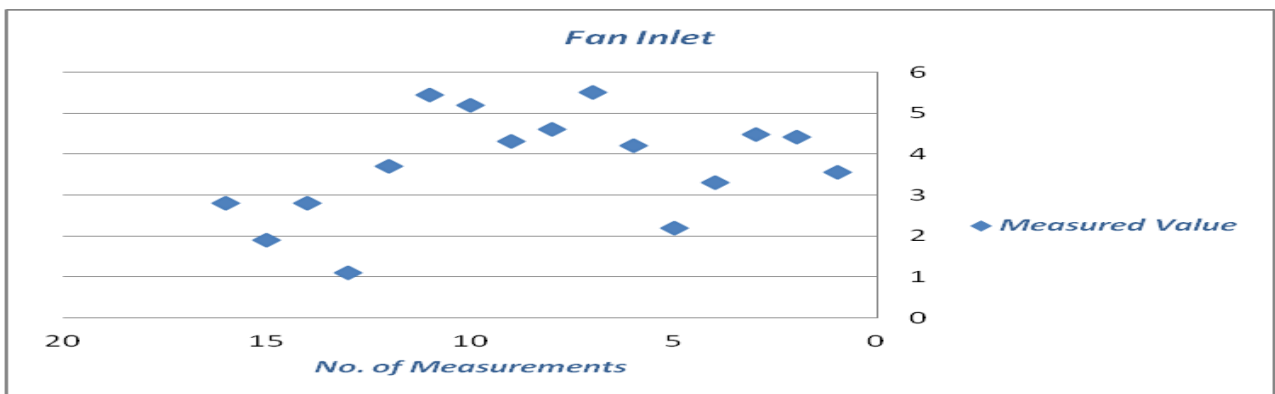
The design water flow rate of closed circuit cooling water system according to the flow diagrams and nominal bores are stated in table.2. Total Water flow is assumed as 1200 lit/min. Actual flow rates of water passing through the system is about half this amount.

Operating area	Nominal Diameter	Flow Rate( lit/min)
<b>Main Branch</b>	<b>125</b>	<b>1450</b>
<b>Under Operating Room</b>	<b>100</b>	<b>850</b>
<b>Radiators above cutting manhole</b>	<b>80</b>	<b>600</b>
<b>Radiators on Skärstation Walls</b>	–	<b>600</b>
<b>Total Cooling Water Flow Rate</b>	–	<b>1200</b>

**Table 2: Design Water Flow Rate for Closed Circuit Water System**

### 3.3 Measurement Uncertainty and Errors

In order to get true value a calibration of a measurement instrument results should be added to the measured value. The reduction factor for fan inlet measurement is  $1/\sqrt{16} = 0.25$ . The reduction factor is ok when the measurement factors are mutually uncorrelated. Correlated data occur when speed of sample data is faster than variation. In our cases the adjacent values are not so close and it is not possible to estimate a certain value. Consequently the adjacent measurement values are not severally correlated. The autocorrelation does not attribute here. By increasing the number of measurements and time intervals between the measurements can be useful in the uncertainty calculations.



**Figure 31: Example of Uncorrelated Measurement**

In some cases such as cooling water measurement we did not have the possibility to repeat the measurement we can only take one or two samples and we can not make estimation of type A uncertainty (Random uncertainty of the measurement).

According to the measurements on 2011.11.06 Velocity and temperature contours in the inlet of the supply fan are drawn. Energy consumption of the fan can be survey by detail study of available data of fan inlet damper measurement.

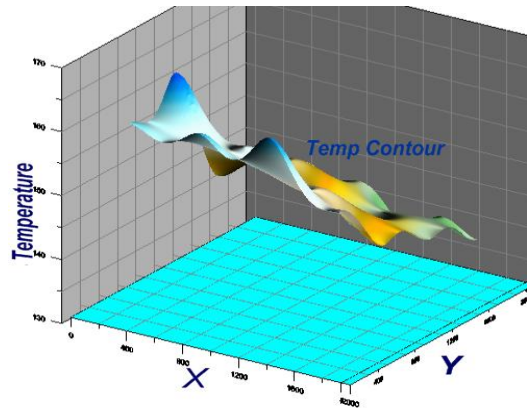


Figure 32: Temperature Surface Data Fan Inlet

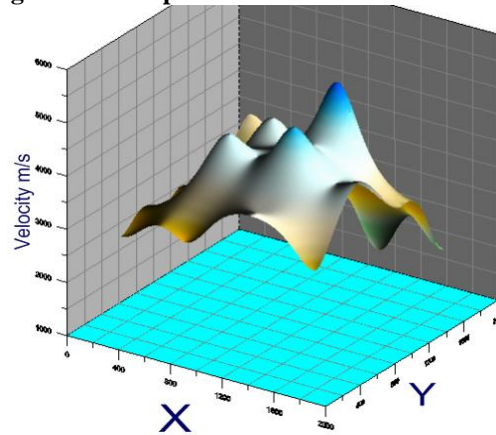


Figure 33: Velocity Surface Data Fan Inlet

### 3.4 Heat Loads and Energy Consumption Study

Radiation and Convection heat from material assumed as heat generation or heat gains, cooling water and air cooling system loads are assumed as heat losses to the working area. In heat balance calculations we add heat generation and subtract heat losses to find total amount of energy need inside the working area.

In the following table Average heat Load Calculations for a sample production date will be found. Calculations are based on Design temperature of 28°C, details calculation will be found in attached file:

**Average Temp inside Skärstation: 28°C**

**Average Temp inside Fan Room: 14, 03°C**

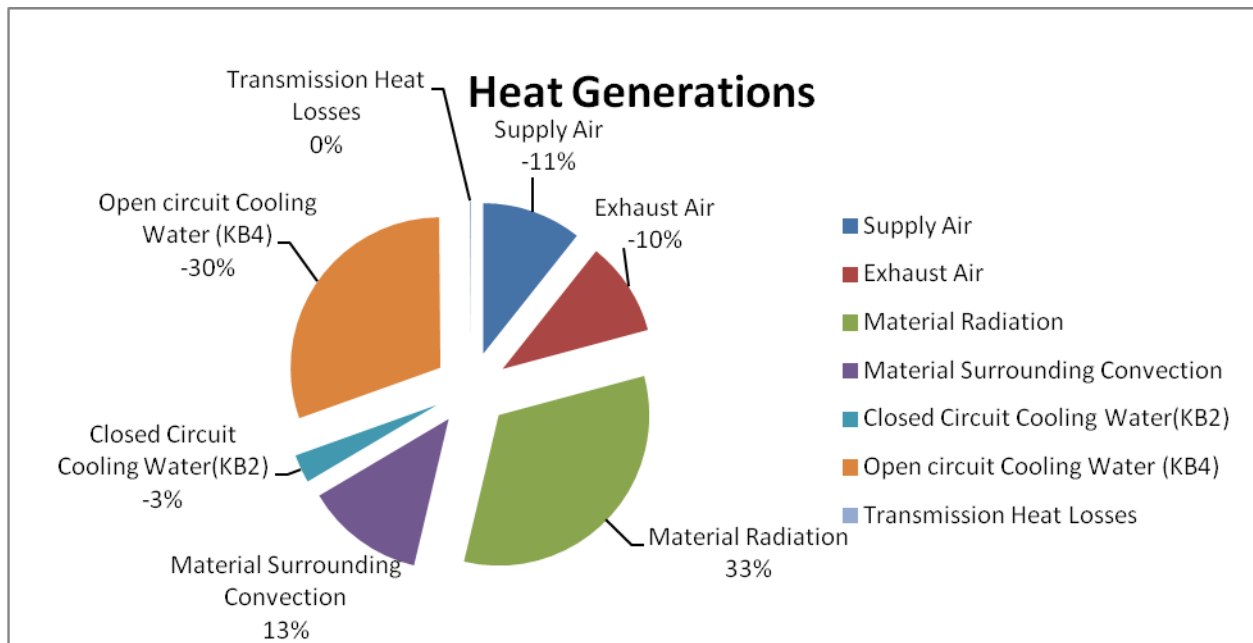
No.	Heat Source	Heat Amount(Watt)	Percentage of Heat Amount
1	Supply Air	-268800	13%
2	Exhaust Air	-255360	12%
3	Material Radiation	+828668	33%
4	Material Surrounding Convection	+322133	13%
5	Closed Circuit Cooling Water(KB2)	-76633	3%
6	Open circuit Cooling Water (KB4)	-763749	30%
7	Transmission Heat Losses	-3541	0%
<b>Total Heat (W)</b>		<b>-213741</b>	

**Table3: Actual Heating Generations for Desired Temp**

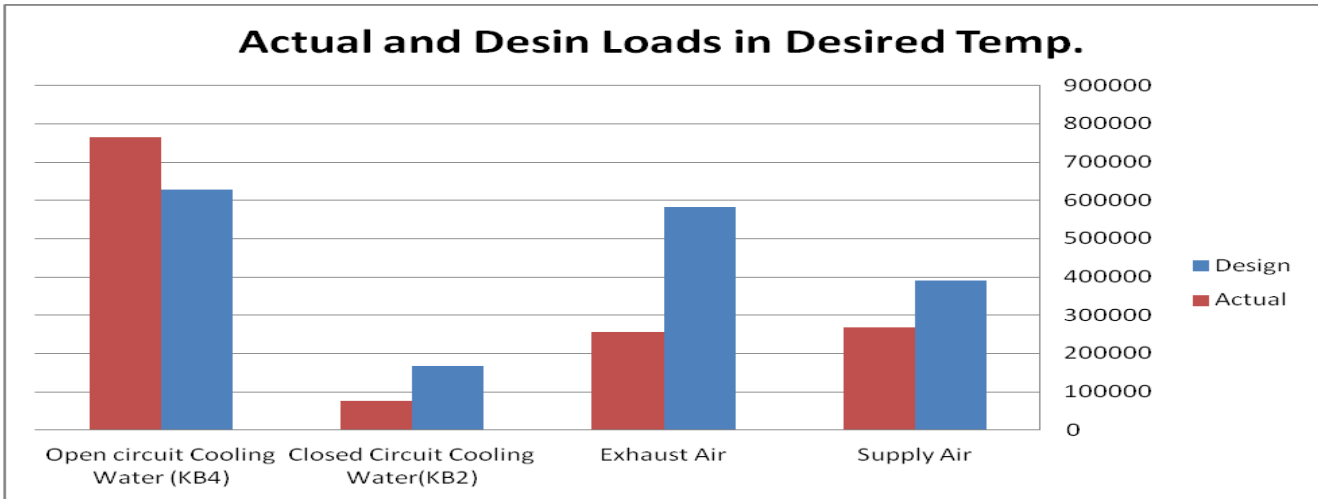
Table.3 shows actual heat losses and heat generations when inside temperature is about 28 °C. Negative amount for final heat generation in table.3 shows that cooling systems can cover heat generations via material convection and radiation at that situation and we do not need extra cooling system when inside temperature is 28 °C but in actual situation the temperature is higher than this amount through production hours. Figure.35 shows percentages of different heat losses and heat generations for table3. We consider that material radiation produces about 33% of total heats and Open circuit water system is about 30 % of that amount. We should consider that despite open circuit cooling water allocate about 760000 watt in cooling system, but this system is a local cooling system and maybe it cannot supply the entire amount in whole area.

The graph shows that closed circuit cooling water allocate only 3 percentages of all heat losses. The low amount is according to high decrease of cooling water flow. It can be seen that transmission heat losses is a very tiny part of total heat losses and graph calculate zero percentage for this type of loss.

In the calculation part, ventilation heat losses divided into two different parts (Supply and Return). By variation in inside temperature both supply and return air losses will be changed. Therefore according to find more accurate results this separation was considered.

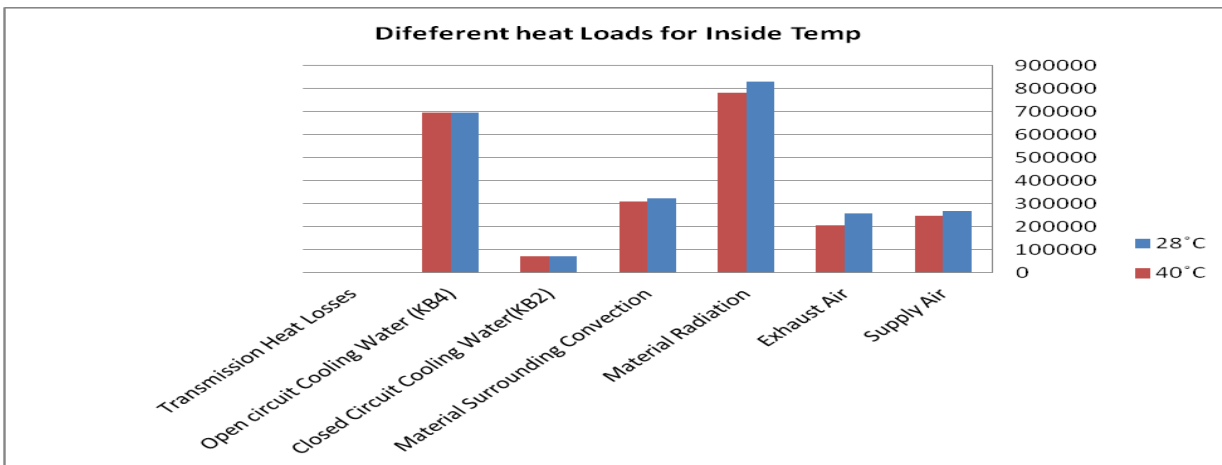


**Figure 34: Percentage of Different Heat Losses inside Skärstaion in Specific Date**



**Figure 35: Comparison Chart between Actual & Design Loads in Desired Temp**

The above chart compare actual and design loads in the same inside temperature (28°C). Design situation amounts calculated when the Air cooling and water cooling flow rates are same as mentioned amounts on drawings. The main difference between two situations is the heat loads for closed cooling water system and ventilation air. Efficiency of all cooling systems decreases. Negative amount for total heat indicates that the design system can cover all heat generation in desired temperature. The percentage of every heat losses and heat gains are almost same as previous table.



**Figure 36: Comparison Chart between Loads in different inside Temp**

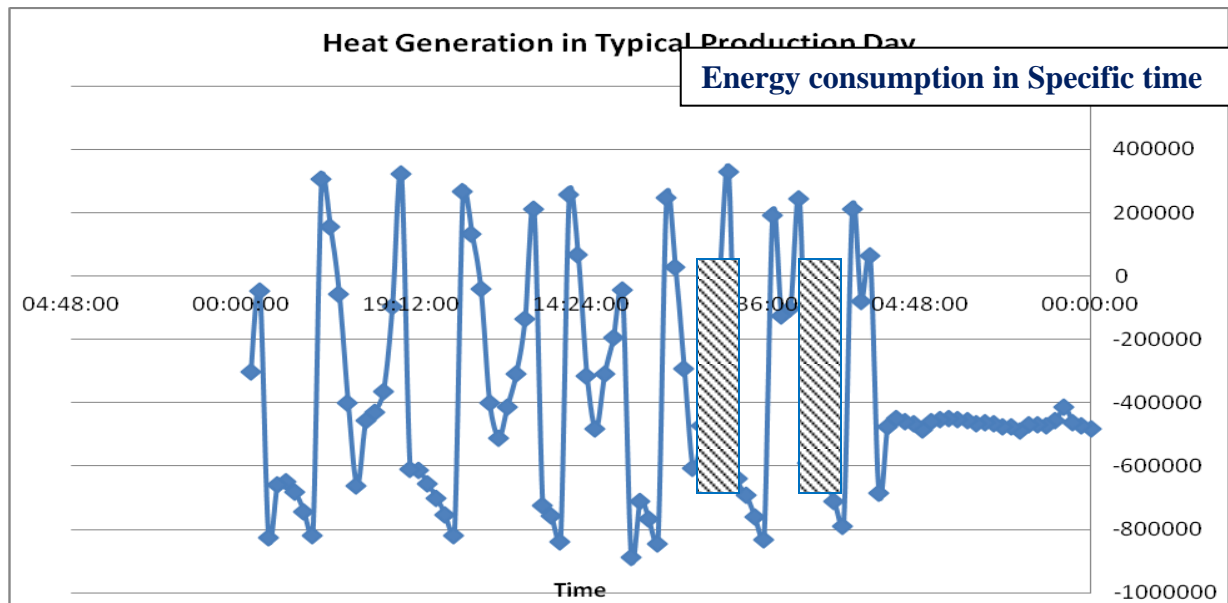
Figure.34 shows a comparison between different heat losses and heat generation in two different assumed inside temperature. Above chart shows that by increasing inside temperature ventilation heat

losses decrease and we need less power in ventilation system. Another observation according to this variation is decreasing in material heat generation loads which have high effects on the total energy consumption inside the working area. Final results in heat calculation shows that by increasing inside temperature total heat loads decreases and cooling system can cover the heat generation in that situation. Despite this low amount of heat load we need to find a way to decrease inside temperature. Actually cooling consumption will increase in that situations and high energy costs are predictable.

<i>Time</i>	<i>Inside Temperature</i>	<i>Total Heat Load(Watt)</i>
<b>07:00:00</b>	<b>30.4766</b>	<b>245367.44</b>
<b>07:15:00</b>	<b>40.2148</b>	<b>-101722.2</b>
<b>07:30:00</b>	<b>40.9336</b>	<b>-127341.1334</b>
<b>07:45:00</b>	<b>31.9531</b>	<b>192740.9453</b>

Above table shows two shifts in inside temperature that varies total heat load from positive to negative when we have about 10 degree changes in inside temperature. Calculations consider that for inside temperature of about 30 °C total heat losses is positive which shows cooling equipment can not cover material heat generation. When inside temperature rise to 30°C the maximum amount of energy needed. For above and below temperature normally total heat losses are negative.

In order to control inside temperature we need some energy consumption survey during the production hours inside cutting line. Below chart show heat generation variation in typical production day, maximum heat losses is about 600000 watt. Total heat losses are normally negative which shows that cooling procedures can cover the heat generations by material. Positive amounts occur when heat losses are less than heat generations. Areas between the graph and vertical axis are equal to energy consumption in any specific times. The areas above the zero are equal to amount energy needed for covering heat generations inside cutting line. Calculations show that minimum energy consumption occurs when inside temperature is about 20 °C through a production period (135 minute).



**Figure 37: Heat Variations during Typical Production Day**



### 3.5 Temperature Variation Study

In order to find the effects of different cooling system, the temperature variation study inside the cutting line is required. At first we need to study the available temperature variation inside working area. Below chart shows temperature variations inside cutting line according to the information from installed data loggers on specific date (2012.01.21). Chart shows high variation from about 15°C to 60°C. Inside temperature rises up to about 65°C in different day-hours.

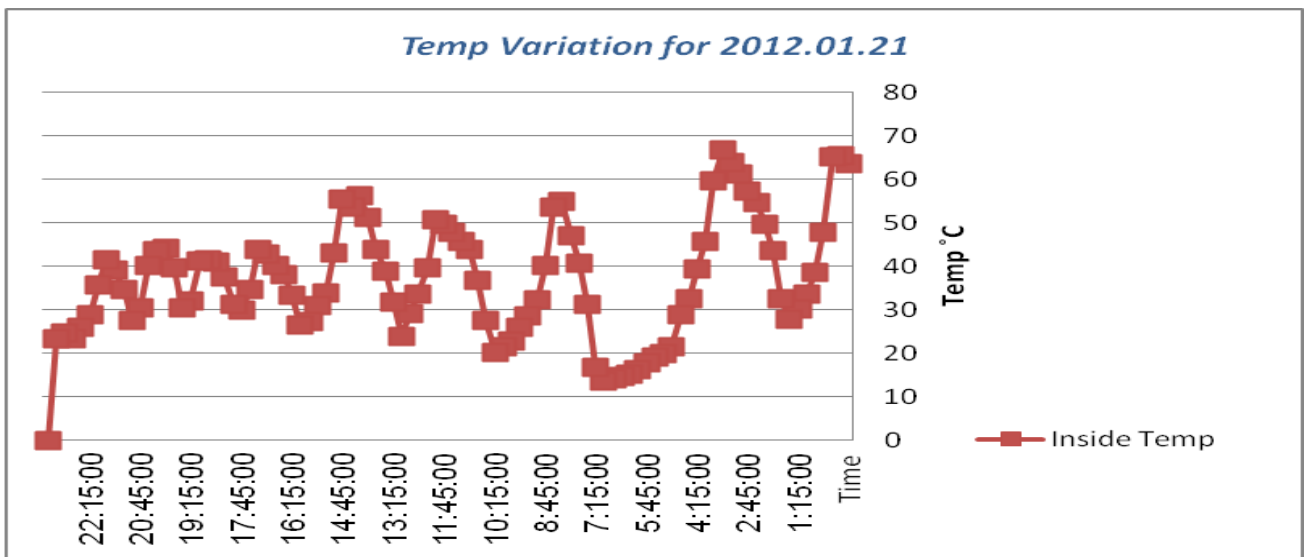
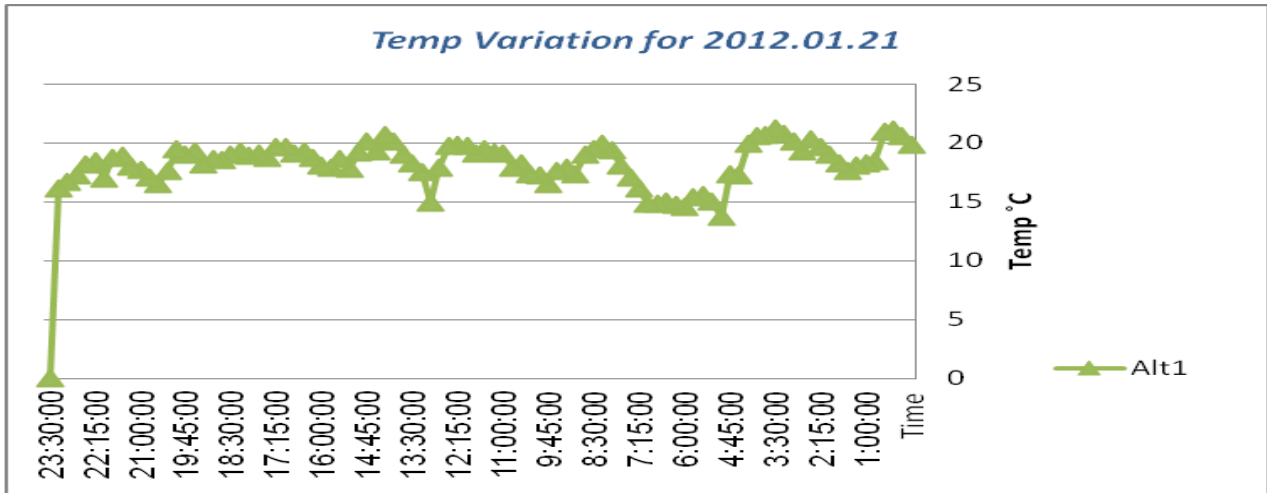


Figure 27: Temperature Data Range in specific Date

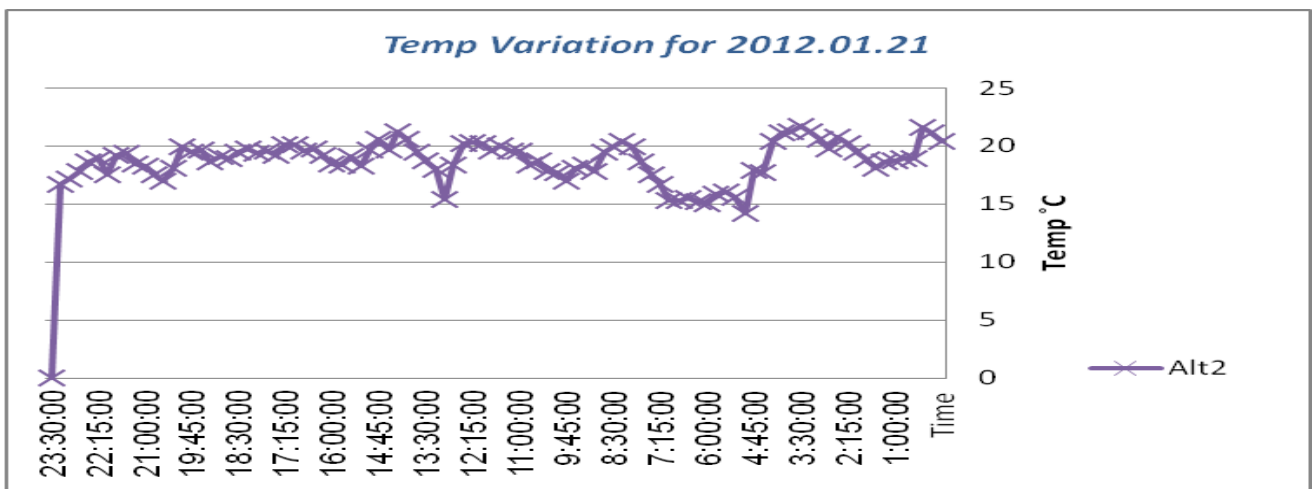
#### Temperature variations survey for 3 alternatives:

**Alternative 1:** In the first alternative temperature variations define when both air cooling and water cooling system work same as primary design systems. In the primary system open circuit cooling system flow rate is approximately same as preset system, closed circuit cooling water worked with almost double flow rate of present system ( 1200 lit/min). Flow rate of air cooling system in design situation is about 30000 m<sup>3</sup>/hr and average inside temperature is about 18°C. By applying both cooling system variation charts will be smoother.



**Figure 28: Temperature Variation for Alternative 1**

**Alternative 2:** In the second alternative ventilation system assumed as design system with 30000 m<sup>3</sup>/hr flow rate and water cooling system supposed as available working system with about 600 lit/min flow rate. Temperature variation obtained according to the mentioned assumptions. Average inside temperature is about 18.8°C in this alternative. Amount of reducing temperature shows that ventilation system is more effective that cooling water system and we can decrease temperature strongly.



**Figure 40: Temperature Variations for Alternative 2**

**Alternative 3:** In the third alternative, water cooling system assumed as design system and air cooling system is supposed as the available working system. Ventilation system flow rate is about 16000

m<sup>3</sup>/hr and water flow rate is 1200 lit/min. Average inside temperature is about 22°C in this alternative.

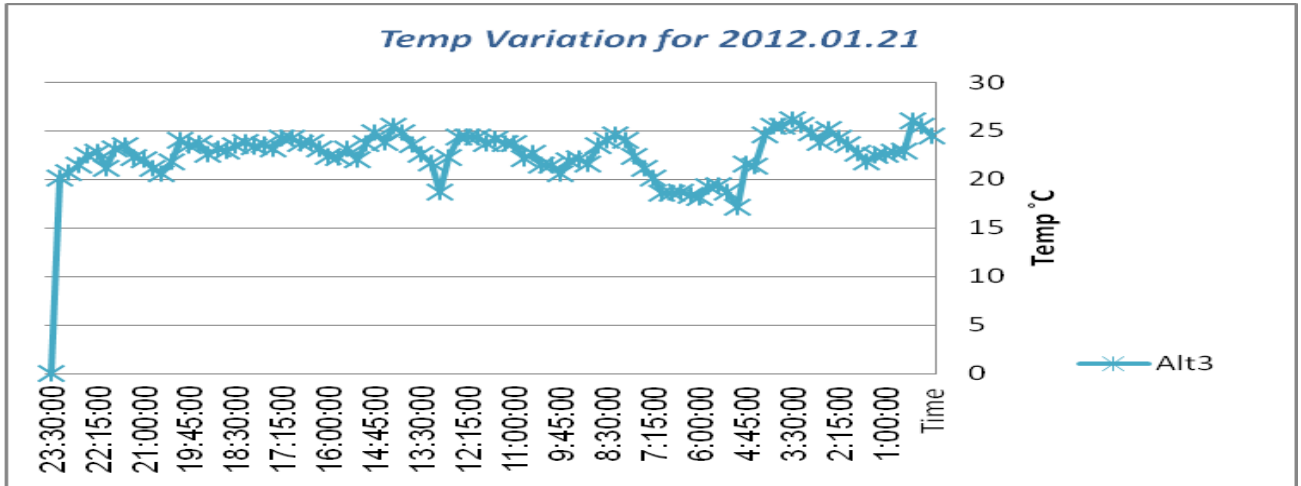


Figure 41: Temperature Variations for Alternative 3

On below figure three alternatives are comprised, according to the previous assumption we will reach the lowest inside temperature by applying both air cooling and water cooling system.

Current results should not be a realistic measure of implemented cooling strategies. Because they only represent temperature studies through winter conditions. For defining the best strategy, the studies should be carrying out for every season.



Figure 42: Comparison Between 3 Alternatives



### **3.6 Suggestions for Improving Ventilation System**

Actually there are not many differences between assumed system in drawings and available system, but in more industrial systems air cooling systems has the main role in controlling temperature. Efficient HVAC control is often the most cost effective options to improve the energy efficiency of any area. New HVAC system must be complemented with an efficient control scheme to maintain desirable inside temp. Efficient control will be reduced energy use by keeping process variables (temp, pressure) to their set points.

#### **3.6.1 Fan Performance Curves**

Usually high operating costs are often caused by inefficient fan operation. Ducting system was designed to pass the desired flow rates but actual amount of flow rate is half of the desired amount. According to working under low flow rates condition, the safety and reliability of fan reduced and the whole system can fall in risk. The decreasement can be according to the duct leakage or supply fan flow rate. Operation curves show that with design (30000 m<sup>3</sup>/hr) amount of flow rate and  $p=100$  pas, fan rpm and total power of the fan will be about 400 rpm and 2 Kw. In the new available flow rate (16000 m<sup>3</sup>/hr) at same pressure drop fan rpm and fan power will be about 250 and 0.7 kw which is actually outside of the fan operation curves . Fan efficiency also decreases through this shift.

#### **3.6.2 Designing new type of Ventilation System**

Available air cooling system is mixing displacement system. As mentioned in introduction part, despite economic objections some alternatives are available for converting a MVS (Mixing ventilation system) system to a DVS (Displacement Ventilation System) system. The system of combined cooled ceiling and displacement can provide better indoor quality with proper design. The new system can strongly raise efficiency of the air cooling system. In that case new ducting system should be designed and cooling air enter near the floor and outgoing by return duct below the ceiling. Installing new type of ventilation system requires high amount of costs.

### **3.6.3 Applying outside Fresh Air in winter**

By opening outside wall damper in the fan room, heat losses will be decrease about 50000 watt with the available ventilation flow rate and cutting line temperature could be decreased to about 30 °C. The procedure only resulted in winter periods and in summer we need to find new solutions.

### **3.6.4 Consider Multiple Fans**

By combining fan in both parallel and series we can achieve to desired air flow without increasing in system size. Parallel model is installing two or more fans side by side. The volume flow rate of two fans will be doubled in desired operation situation with low resistance.

In series operation, fans are installed behind each other. The best outcome is increasing in static pressure into double amount in high resistance system.

In both series and parallel operation, fixed areas on combined operation curves are unstable and should be avoided. This instability is unpredictable.

It is important how to design the layout of the system. The preferred method is pressurizing the enclosure. Pressurized enclosures prevent dust entering and increase the fan life and reliability. The disadvantage of the layout is that fan generates heat dissipated into enclosure [26].

### **3.6.5 Economizer Damper Installation Inlet of Fans**

The operation of economizer dampers if they are not functioning in proper and optimal manner can cause high energy consumption in fans. This will mainly be due to high pressure drop through those dampers which should be developed by supply or return fans. It is necessary to find some strategies for installing optimally economizer dampers to minimize fan energy use. Properly implementing damper can provide energy saving about 5-30% depending on the no. of operating hours, damper characteristics and outdoor air temperature. Several factors such as building location, system characteristics, duct surface resistance and supply air temperature which cannot be considered in this study should be evaluated [18].

### **3.6.6 Return Air Canal to the Filter house**

According to deliver the required air flow of working place, through long length return air canal, installation of more powerful fan or making some modification in the system are needed and



always costs energy. Increasing the pressure of the fan also increases the amount of leakage inside the ducts. The modification of the ducting system would be increasing the diameter and improving leakage conditions. Installing leak free ducts includes minimum costs for delivering required flow rate to the end of the ducts. In this situation applying a bigger fan is not most effective solutions. More effective management of ducting routes could reasonably expect to a healthier working place environment [19].



#### **4. Discussion and Conclusion**

Results show that the main differences between primary calculations and actual calculations are in both Air cooling system and closed circuit cooling water system. Radiators are removed and the amount of flow rates in supply and return pipes are about 50 % of design flow rates which mentioned on drawings. Retrofitting construction needed to achieve to the desirable situation. Results show that the impacts of changing system on air conditioning loads are strongly time dependent, intensifying electrical demand during production peak periods and increasing air conditioning run times.

Little variations in inside temperature cause to high incense of energy consumption. The best way for controlling energy usage in the system is trying to keep inside temperature constant. By controlling inside temperature we can also optimize energy consumption and the optimal amount occurs when inside temperature is about 20 °C

#### **Air Cooling System and Possible Changes in existing Ventilation System:**

According to the detail calculation by increasing the ventilation air to double amount (about 32000 m<sup>3</sup>/hr) we can decrease inside temperature 20 °C and we can reach to about 18 °C inside temp.

- Increasing fan efficiency by revising and checking fan operation curves and retrofitting available ducting rout
- Designing and Replacing displacement ventilation system instead of available mixing ventilation system
- Apply outside air as fresh air into fan room in winter
- Installing Multiple Fans
- Installing economizer damper inlet of the fan
- Changing rout of exhaust air and installing new filter system

### **Water Cooling System and Possible Changes in existing cooling water system:**

If water flow rates of closed circuit cooling water increase to design flow rates (about 1200 Lit/min) we can also decrease inside temperature about 12 °C in same heat generations.

- New heat exchanger added to the network
- Changing in heat duty of coolers (radiators)
- Changes in process which influence on the conditions of return water which consequently effects on the cooling water performance

Many reasons can be assumed for decreasing of water flow in closed circuit cooling water:

- Crime generated inside the pipelines routes from the heat exchanger to the radiators
- Weared out and rusty water cooling equipment such as radiators

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## APPENDECIES

### APPENDIX I: Air Flow Measurement Device Overview

The VELOCICALC PLUS measures air velocity, temperature, differential pressure, and calculates volumetric flow rates. In addition measures relative humidity and calculates dew point from the temperature and relative humidity readings. The VELOCICALC PLUS can store individual readings and compute the average of these readings. The device can be powered in two ways: four size AA batteries or the optional AC adaptor. The device is capable of displaying the measured values in several different measurement units. Choices of measurement units: [20]

Velocity: ft/min, m/s

Temp: °C, °F

Flow Rate: ft<sup>3</sup>/min, m<sup>3</sup>/hr, and l/s

Pressure: in. H<sub>2</sub>O, mm Hg, Kpa

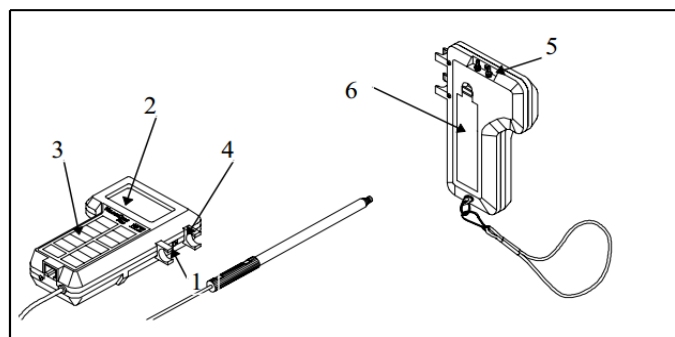


Figure 29: Valocicalc Plus



1. On/Off Switch
2. Display
3. Function Keys
4. Probe Mounting Clips
5. Battery Access cover

### **Standard Velocity vs. Actual Velocity:**

Since thermal air velocity sensors are sensitive to changes in air density and air velocity, all thermal anemometers indicate velocities with reference to a set of standard conditions. For TSI instruments, standard conditions are defined as 70° F (21.1° C) and 14.7 psia (101.4 kPa). Other manufacturers may use different values.

Standard velocity is the velocity the air would be moving if the temperature and pressure were at standard conditions. It is usually the most useful measure of airflow because it defines the heat-carrying capacity of the air. Actual velocity is the velocity at which a microscopic particle of dust would be traveling if it were in the air stream. In some instances, actual air velocity rather than standard velocity may be of interest. To obtain the value for actual velocity, multiply you standard velocity by the following density correction factor:

$$ActualVelocity = (StandardVelocity) \left[ \frac{460 + T}{460 + 70} \right] \left[ \frac{14.7}{P} \right]$$

Where

T: Ambient Temp in degree Fahrenheit

P: Ambient Pressure in Psi

If you use metric unit the equation becomes:

$$ActualVelocity = (StandardVelocity) \left[ \frac{273 + T_m}{273 + 21.2} \right] \frac{101.4}{P_m}$$

T<sub>m</sub>: Ambient Temp in degree Celsius

P<sub>m</sub>: Ambient Pressure in Kpa

## APPENDIX II: Temp Measurement Device Overview

### SKFCMSS2000



Figure 30: SKFCMSS2000

The instrument features object temperature between -25 °F to +1100 °F (-32 °C to +600 °C). The device senses emitted, reflected and transmitted energy. This energy collected onto a infrared detector. Electronics part convert information to a temperature reading on the backlit display. The thermometer stores up to 12 data locations. The noncontact thermometer senses the energy of an object with an infrared detector. When pointed at an object, the infrared detector collects energy producing a signal that the microprocessor translates as a reading on the backlit display. As the trigger is squeezed, the object temperature is continuously measured by the infrared detector. To achieve an accurate temperature reading, unit must be the correct distance from the



targeted object. A singular laser spot highlights the approximate center of the spot measurement area. This spot measurement area gets larger farther away you are from the target. The ratio of the distance to spot size or D:S, is shown on figure.32 [21].

### Specifications

**Temperature range:** -32 °C to +600 °C (-25 °F to +1100 °F)  
**Accuracy [assumes ambient operating temperature of +23 °C (+73 °F) at calibration geometry]:**  
**For targets above +23 °C (+73 °F): ± 1% of reading or ± 1 °C (± 2 °F), whichever is greater.**  
**-18 °C to +23 °C (0 to +73 °F): ± 2 °C (± 3 °F)**  
**-26 °C to -18 °C (-15 °F to 0 °F): ± 2.5 °C (± 4 °F)**  
**-32 °C to -26 °C (-25 °F to -15 °F): ± 3 °C (± 5 °F)**  
**Repeatability: ± 0.5% or ≤ ± 1 °C (± 2 °F), whichever is greater**  
**Response time: ≤ 0.5 second (95% of reading)**  
**Spectral response: 8 to 14 μm**  
**Emissivity: Digitally adjustable emissivity (from 0.1 to 1.0 by 0.01)**  
**Ambient operating range: 0 to +50 °C (+32 °F to +120 °F)**  
**Relative humidity: 10% to 90% relative humidity noncondensing, at < +30 °C (+86 °F) ambient**  
**Storage temperature: -20 °C to +60 °C (-13 °F to +158 °F) without battery**  
**Weight: 320 g (11 oz)**  
**Dimensions: 200 mm x 160 mm x 55 mm (8" x 6" x 2")**  
**Power: 9 V Alkaline or NiCad battery**  
**Typical battery life (Alkaline):**

- 20 hours (with laser and backlight on 50%)
- 40 hours (with laser and backlight off)

**Laser sighting (Class II): Extra bright laser point**  
**Typical distance to target: 5 meters (15 feet)**  
**Distance to spot (D:S): 30:1 at focus point**  
**MIN, MAX, AVG, DIF, temperature display**  
**Data logging: 12 points**  
**Probe jack**  
**Display hold: 7 seconds**  
**Hi / low alarm**  
**LCD backlit**  
**Temperature display: °C or °F selectable**  
**Display resolution: 0.1 °C (0.1 °F)**  
**Hard carrying case**  
**Locking trigger**  
**Tripod mounting: 6.35 mm (1/4-20 UNC threading)**

### APPENDIX III: EUROSONIC 2000 HH

The hand held flow meter is a battery powered ultrasonic flowmeter based on transit time flow measurement principles. It measures flow rate from outside of the pipes by a pair of ultrasonic transducers. The pipes should contain full liquids and little particles or bubbles. Liquids can be water (hot water, chill water, city water, sea water, etc.); sewage, oil (crude oil, lubrication oil, diesel oil, fuel oil, etc), chemicals (alcohol, acids, etc.), waste, beverage and liquid food, solvent and other liquid. The built in data logger can store 2000 lines of data which downloaded to a PC through its RS 232 connection port.

When fluid is flowing, signal transit time in downstream direction is shorter than in upstream direction, the difference is proportional to flow velocity. Eurosonic 2000 HH measures this value and converts it to flow rate via pipe diameter. Clamp on transducers are magnetically or mechanically installed on the other surface of the pipe where the flow has to be measured [22].

#### Specifications

Accuracy	±1 to 3 %
Linearity	0.5 %
Repeatability	0.2 %
Response time	1 to 999s
Velocity	0~30 m/s
Range ability	500:1

Measurement Parameters Instantaneous flow rate totalized flow (4 tantalizers) velocity



Figure 31: Hand Set inside suitcase



#### APPENDIX IV: Plate Type Heat Exchanger

In plate type heat exchanger, heat transfers through metal plates. In this type of heat exchanger heat transferring area are much larger than conventional model. This large surface also cause to icreasement in speed of temperature rise. Dr. Richard Seligman invented Plate type heat exchanger (PHE) on 1923. It consists of two medium and low pressure fluids. The temperature approach in a plate heat exchanger is about 1 °C in accordance with shell and tube heat exchanger wich need up to 5 °C and more [23].

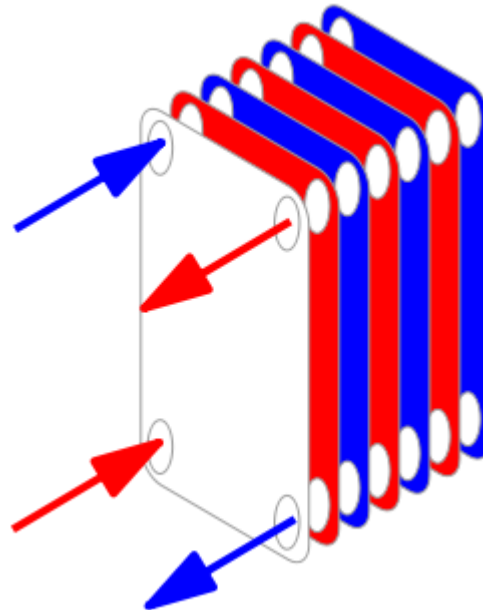


Figure 32: Schematic Conceptual Diagram of a Plate and Frame Heat exchanger

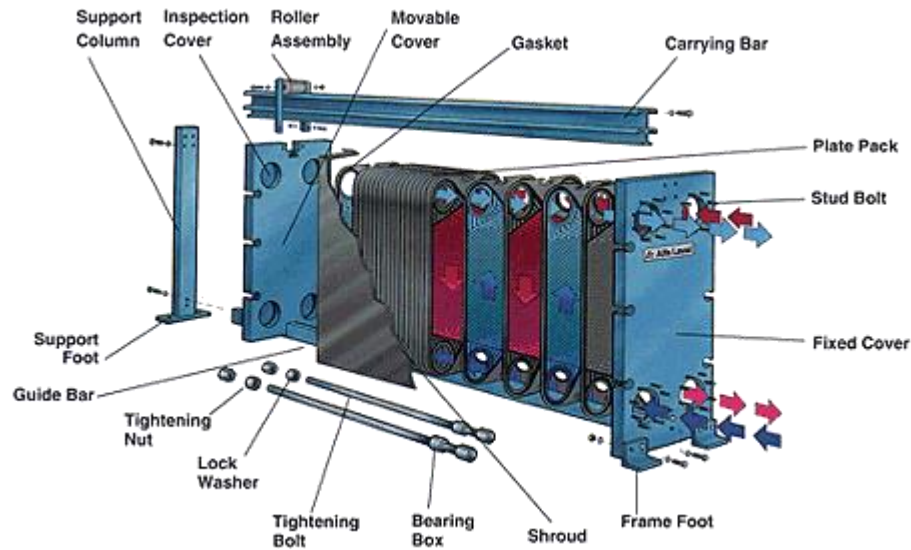


Figure 33: Different Parts of Heat Exchanger

**Plate Type Heat Exchanger Model M15-BFG8 Alfa Laval**

<b>Max. Flow Rate(kg/s)</b>	<b>80</b>
<b>Max Temp(°C)</b>	<b>160</b>
<b>Max Pressure(bar)</b>	<b>16</b>
<b>Height(mm)</b>	<b>1885</b>
<b>Width(mm)</b>	<b>610</b>
<b>Connection size Flange(mm)</b>	<b>140</b>
<b>Flow Principle</b>	<b>Parallell</b>
<b>Manufacturing Date</b>	<b>1999</b>

Entering water temperature to heat exchanger is about 28 °C and Leaving Water temperature is 32 °C which is the amount of temperature entering to the radiators.

## **APPENDIX V: Supply Cooling Fan**

Main Ventilation fan is NBA 125 BAHCO Company in the following part you can find charts and tables related to this type of ventilation fan:

BAHCO Radial fans, Single inlet, are belt driven for transport of clean air/gas in facilities for ventilation and air conditioning. Fans have backward blades which provide high efficiency with low noise [24].

### **Specifications:**

- Flowrate to 30 m<sup>3</sup>/s
- Pressure droop to 1500 Pascal.
- 86 % efficiency in optimal line, can be considered at least 80 % through flow and pressure
- Can be completely delivered with factory installed belt driven motor.
- Can be installed, inside or outside.

### **Description**

Extraction fan are mounted on a beam frame which also have a plate for the motor. Between sizes 050-090 are covered undevied and with certain restrictions can be installed on any outlet loactions. Sizes between 100-125 can covered totally or individually as ordered. Sizes 140-160 are always supplied with split casing.

All fans can be equipped with drain connections and installed grills on outlet.

### **Material**

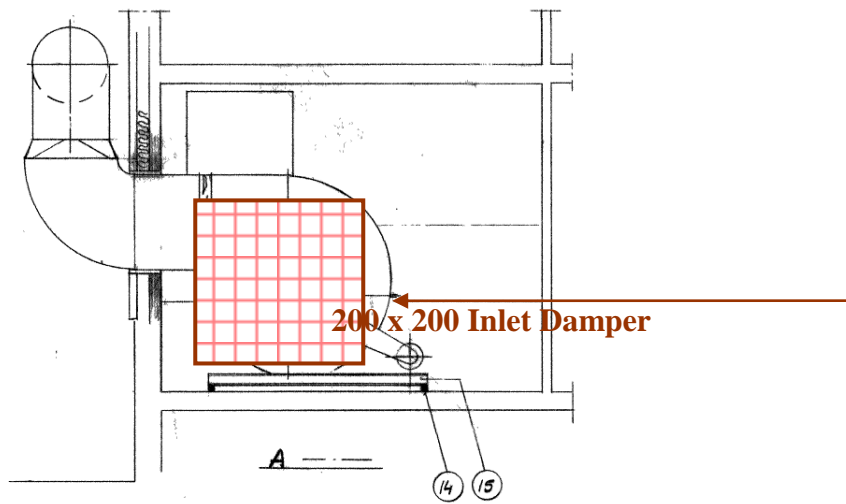
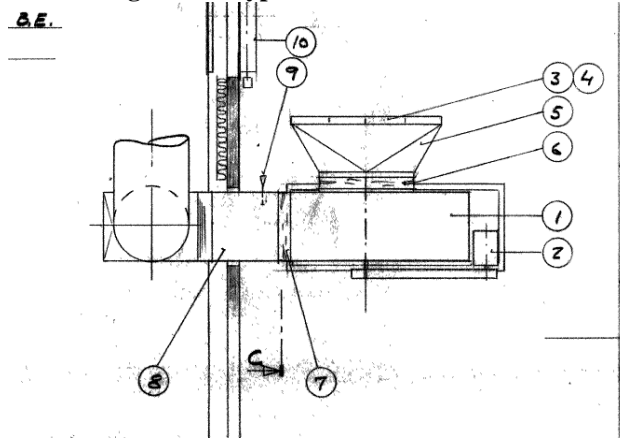
Prime steel and Galvonized steel plate.

Capacity Overview

Diagran Figure 37,Shows work area with the limits of not less than 75 % efficiency.

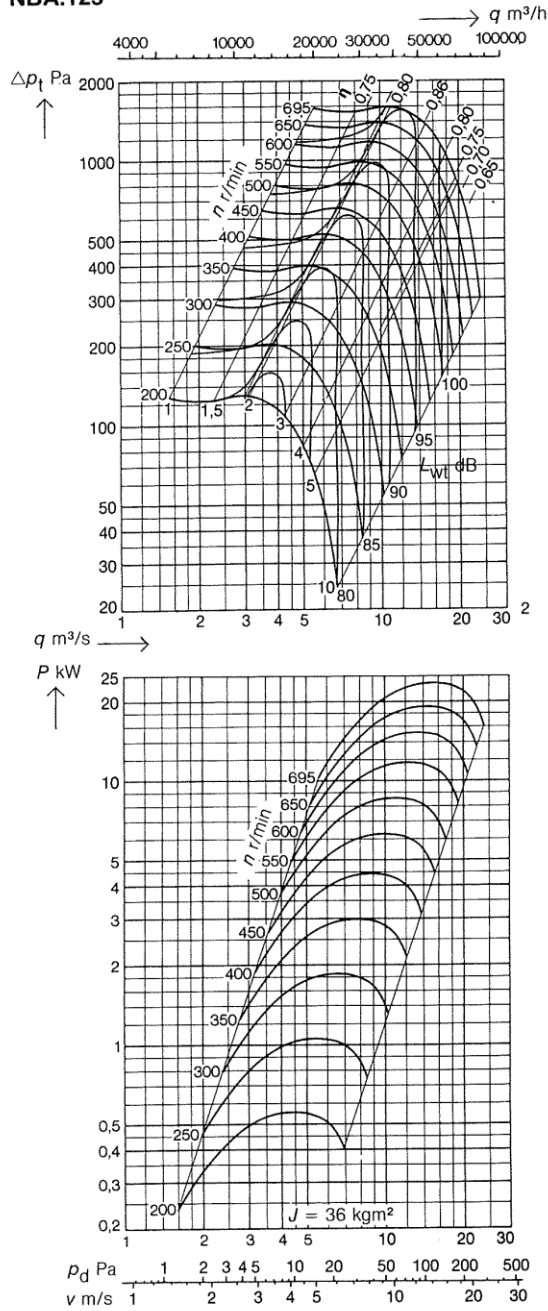


**Figure 34: Typical Radial FAN**

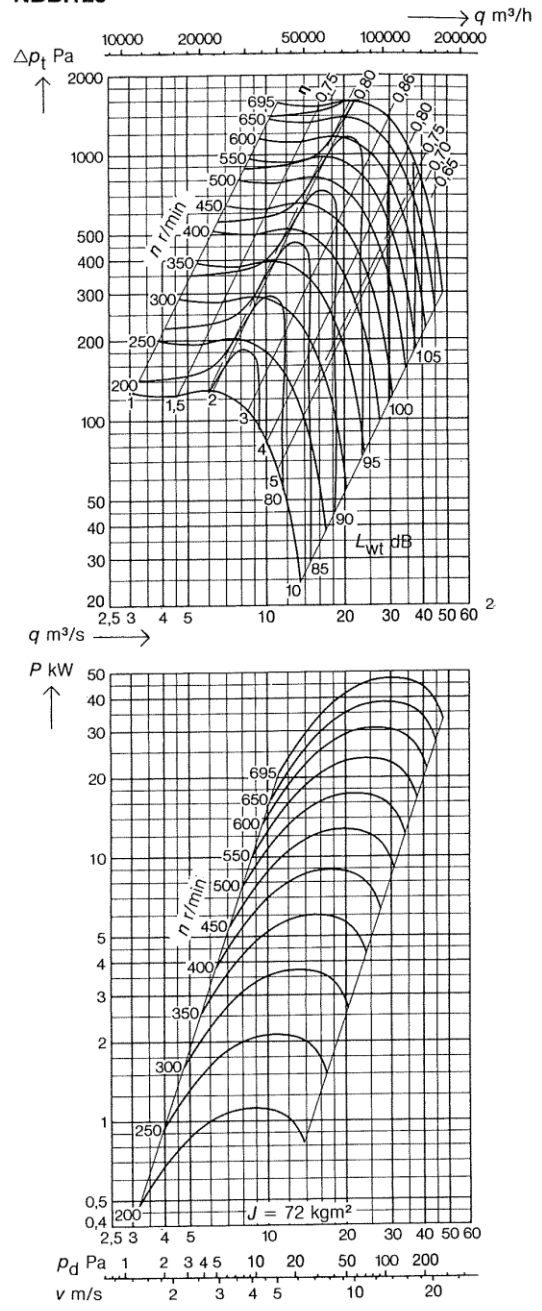


**Figure 35: Cooling Fan Plan and Section**

**NBA.125**



**NBB.125**



**Figure 50: NBA 125 Operation Curves.**



## Appendix VI: Heat Load Calculation for Desired indoor Temperature 28 °C

2011-01-05

### 1. Supply Air

Average inside Temp: 28°C

Average Fan Room Temp: 14, 03 °C

Mean Velocity outside Wall Damper: 11, 2 m/s

Mean Velocity outside fan damper: 4 m/s

Wall Damper Flow Rate:  $1,4 \times 1,4 \times 11,2 = 22 \text{ m}^3/\text{s}$

Fan Inlet Flow Rate:  $2 \times 2 \times 4 = 16 \text{ m}^3/\text{s}$

Q supply air =  $1200 \times 16 \times (28 - 14) = 268800$

### 2. Exhaust Air

Return Air Mean Velocity: 16,4 m/s

Average Return Air Temperature when operating: 12°C

Exhaust air Flow rate =  $0,9 \times 0,9 \times 16,4 = 13,3 \text{ m}^3/\text{s}$

Q exhaust air =  $1200 \times 13,3 \times (28 - 12) = 255360 \text{ W}$

### 3. Material Radiation

Total Area of Panels:  $3 \times [(2 \times 7,2 \times 0,365) + (2 \times 7,2 \times 0,265)] = 27,2 \text{ m}^2$

Q radiation =  $5,67 \times (10) - 8 \times 0,815 \times ((900)^4 - (28)^4) = 30318 \text{ W} / \text{m}^2 \times 27,2 = 828668 \text{ W}$

### 4. Material Convection

De 2,1 =  $4 \times \text{area} / p = 0,69$

Q1 =  $1019 \text{ W} / \text{m}^2 = 1039 \times 3 \times 7,2 \times 0,365 = 8190 \text{ W}$

Q2 =  $17361 \text{ W} / \text{m}^2 = 17733 \times 3 \times 0,365 \times 7,2 = 139807 \text{ W}$

Q3 =  $29779 \text{ W} / \text{m}^2 = 15211 \times 2 \times 0,265 \times 7,2 \times 3 = 174136 \text{ W}$

Q total = 322133 W

### 5. Open Circuit Cooling Water, KB4

Beams Flow Rate: 4, 27 l/s

Rolls Flow Rate: 7, 68 l/s



Inlet Water Temp: 14, 2°C

Outlet Water Temp (Canal Water): 28,1°C

$Q_{KB4} = 11,95 \times 1000 \times 4,18 \times 13,9 = 694318 \text{ W}$

6. Closed Circuit Cooling Water, KB2

Actual Flow rate ~ 500 l/m

$Q = 500/60 \times 1000 \times 4,18 \times 2 = 69666 \text{ W}$

7. Transmission Heat Losses

$Q = 0.71 \times 255 \times (28-6) = 3514 \text{ W}$

A total = 255

Interior Heat Resistance  $R_{si} = 0.04 \text{ m}^2 \cdot \text{°C/W}$

Exterior Heat Resistance  $R_{se} = 0.13 \text{ m}^2 \cdot \text{°C/W}$

$\Lambda_{concrete} = 1.7 \text{ W/ m}^2 \cdot \text{°C}$

U Concrete Wall = 0.71 W/m

## Appendix VII: Measurements in Fan Room

6 Dec 2011, 8:30

Outside Wall Damper is closed

Fan Inlet Damper

No.	Velocity(m/s)	Temperature(°C)	Relative Humidity (%)
1	2,78	16,1	24,3
2	30	16,2	24,5
3	3,83	16,4	24,7
4	3,13	15,5	25,4
5	2,84	16,5	24,4
6	4,54	15,6	25,8
7	5	15,2	26,8
8	4,29	14,6	26,9
9	2,33	14,5	27,2
10	4,34	15	27,4
11	5,35	14,2	26,8
12	3,34	14,3	27,6
13	3,59	14,3	26,3
14	2,11	14,3	26,2
15	1,7	13,8	26,5
16	2,04	13,9	27

### Inside Wall Damper

No.	Velocity(m/s)	Temperature(°C)	Relative Humidity (%)
1	13,6	12,2	30
2	13,5	11,3	29,6
3	14,5	10,8	30,3
4	11,6	10,6	30,4
5	11,3	9,4	31,3
6	9,14	11,6	32
7	8,75	10,5	30,5
8	5,10	11,3	30,5
9	12,9	10,6	30,5
10	11,7	12,5	22,9

**Measurements in Fan Room**

**20 Dec 2011, 11:30**

**Outside Wall Damper is closed**

**Fan Inlet Damper**

No.	Velocity(m/s)	Temperature(°C)	Relative Humidity (%)
1	3,56	12,6	34,7
2	4,42	11,9	36,3
3	4,48	11,6	36,7
4	3,3	11,7	38
5	2,2	11,5	38,5
6	4,2	12,1	37,7
7	5,5	11,4	38,6
8	4,6	11,4	38,8
9	4,3	11,5	39
10	5,2	11,5	38,3
11	5,45	11,1	38,5
12	3,7	10,8	39,5
13	1,11	10,6	40,3
14	2,8	11	40,2
15	1,9	10,6	40,2
16	2,8	10,2	41,8

### Inside Wall Damper

No.	Velocity(m/s)	Temperature(°C)	Relative Humidity (%)
1	15,7	9,1	40,3
2	11,1	9,9	42,3
3	13	9	42,4
4	11,6	9,2	43,9
5	12,3	9,3	42,9
6	10,9	8,6	44,4
7	10,5	8	44,7
8	8,5	8,3	46
9	10,8	8,8	46,7
10	13,7	8,7	46,2

