CHALMERS
UNIVERSITY OF TECHNOLOGY

Space Requirements for Technical Systems in Office Buildings

Air handling plant room model

Master's Thesis in the Master's Programme Sustainable Energy Systems

EMIL KVIST

Department of Civil and Environmental Engineering
Division of Building Services Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015
Master's Thesis 2015:07

MASTER'S THESIS 2015:07

Space Requirements for Technical System in Office Buildings – Air handling plant room model

Emil Kvist

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Civil and Environmental Engineering
Division of Building Services Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2015

Space Requirements for Technical Systems in Office Buildings – Air handling plant room model

Emil Kvist

Supervisors: Gunnar Isaksson & Göran Andersson, Gicon Installationsledning AB
Examiner: Jan Gustén

Master's Thesis 2015
Department of Civil and Environmental Engineering
Division of Building Services Engineering
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Telephone +46 (0)31-772 1000

Printed by Chalmers Reproservice
Gothenburg, Sweden 2015

Space Requirements for Technical Systems in Office Buildings – Air handling plant room model

Emil Kvist
Department of Civil and Environmental Engineering
Division of Building Services Engineering
Chalmers University of Technology

ABSTRACT

This study illustrates how the air handling plant room geometry depends on the Specific Fan Power (kW/(m^3/s)) and airflow rate (m^3/s) by using a theoretical model. The total shaft area of an office building relate to the gross external area and ultimately examines the possibility to utilize the model together with the shaft area study to investigate various sizes of office buildings share of technical area.

The analysis shows that there is a clear connection between total airflow rate and the air handling plant room area and the model is verified with good results compared with measured data for a number of office buildings. The conclusion is that the model seems to be consistent with reality. The results verifies the well-known and often used in practice graphs published by Enno Abel in 1999, when SFP was not considered to the same extent as today, can be used for air handling plant rooms designed for an SFP $\leq$ 1.5 kW/(m^3/s).

List of Abbreviations

AHU – Air Handling Unit

HVAC – Heating, Ventilation and Air Conditioning

VAV – Variable Air Volume

CAV- Constant Air Volume

RHX – Rotary Heat Exchanger

KPI – Key Performance Indicator

DC – Direct Current

AC – Alternating Current

GEA – Gross External Area

NIA – Net Internal Area

Table of Figures

Table of Contents

1. Introduction

Due to the necessity of space efficient and accessible technical areas, it is important for everyone involved in designing an office building to be aware of the parameters that affects the total space required. This is why this thesis investigates the relationship between floor area and room height, shaft size and location and how these affect the total space required. Other parameters that more specifically affect the air handling plant room size and shaft size is the Specific Fan Power level, SFP.

SFP quantifies the energy efficiency of a ventilation system and is used to make an energy efficient ventilation system design. The space required in air handling plant rooms depends on the size of the air handling unit and the units' size depends on the airflow and SFP level. Because of this, the SFP level plays a large role in how much space is required.

The aim of this study is to understand how the air handling plant room geometry depends on both SFP and airflow by using a theoretical model, how the total shaft area of an office building relate to the gross external area and lastly examine the possibility to further look at the economic impact of this. But also make a brief summary of the other technical systems with respect to space requirement in office buildings.

It is of special interest to verify the results from the theoretical air handling plant room model with existing buildings and therefore having the possibility to estimate how much space the air handling plants need in an early design phase. This results in a faster design with less drawing revisions for architects, HVAC-designers etc. but none the less it is a tool to make an economical evaluation of how much space is needed. This thesis focuses on air handling unit rooms due to its superior space requirement in comparison with the other disciplines.

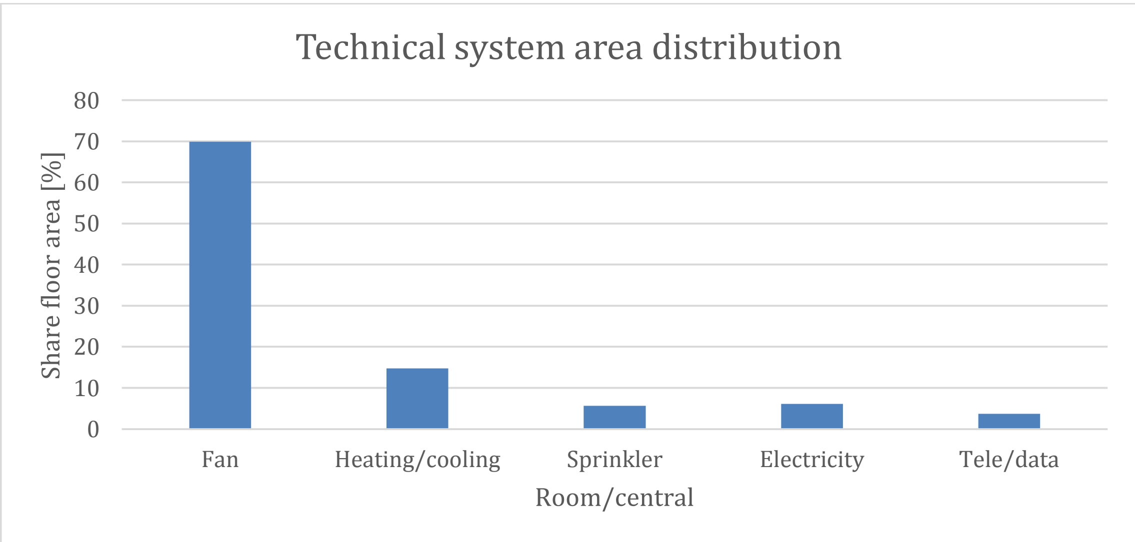
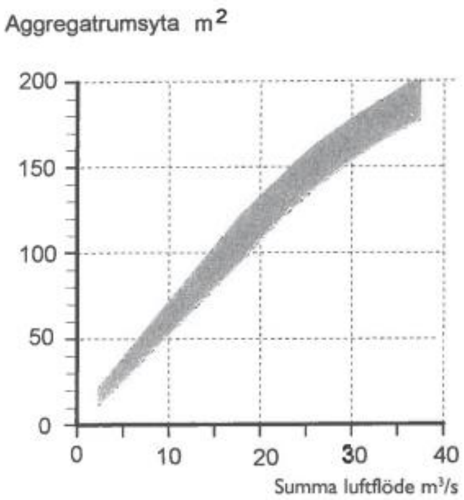


Diagram 1. *Technical system area distribution comparison between disciplines based on four measurements done in existing office buildings.*

1.1 Background

A number of studies have investigated the relationship between airflow and room geometry for air handling plant rooms.

One example is the work made of Enno Abel, former professor at Chalmers University of Technology, who studied areas and heights for air handling unit rooms with respect to total airflow, see Figure 1 and 2. Abel's graphs were published in 1999 and are based on data collected in the 70s.



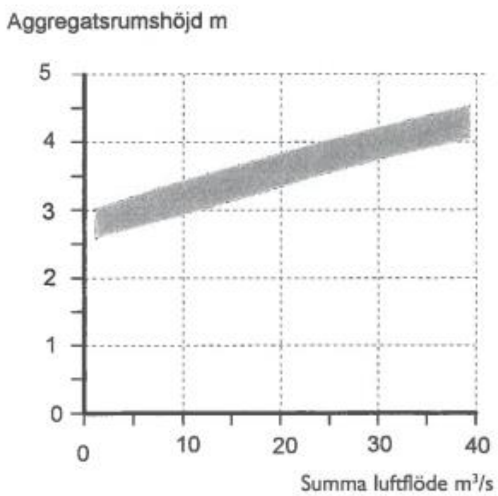


Figure 1. *Abels graph for air handling plant room area versus airflow.* ***Figure 2.*** *Abels graph for air handling plant room height versus airflow. Source: Abel, 1999.*

These graphs are constructed from measuring existing buildings and compiling several of them in to a graph without regard to the Specific Fan Power. Contrary to this work, where a theoretical model is used to construct graphs for the air handling plant room with regard to the Specific Fan Power and compares the result with measured buildings.

The traditional way to estimate the room geometry is illustrated in Figure 3 below, where first the thermal constraints are stated, i.e. the design temperatures, secondly an estimation of the required airflow. With a defined system choice like VAV or CAV, the air handling unit's size is determined. With the geometry of the air handling unit the geometry demands for the air handling plant room can be estimated.

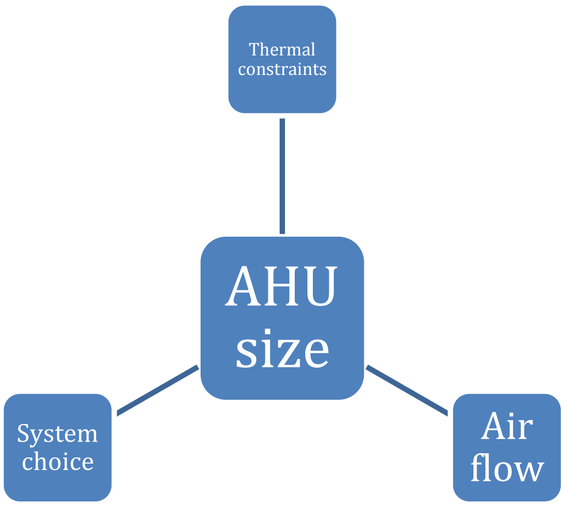


Figure 3. *Systematic strategy to approximate the geometry of air handling plant rooms.*

1.2 Purpose

The purpose of this thesis is to investigate how the Specific Fan Power relates to the total airflow and geometry of the air handling plant room. And at the same time declare parameters that dimension the other technical system areas except the air handling plant room.

1.3 Limitations

In this thesis only office buildings are studied and with a limited selection. For the same reason the air handling plant model is adapted for office buildings with limited number of air handling unit manufacturers and air handling unit geometry calculations.
The model does not consider geometry limitations that must be regarded otherwise, i.e. the positioning of the air handling unit and duct crossings. Further, the number of shafts, location and size of shafts are assumed unlimited with respect to reducing the space required.

All air handling units have the same basic equipment:

- Heat exchanger (rotary, battery or plate)
- Heating coil
- Cooling coil
- Fans
- Dampers at the inlets
- Filter after each damper

In this thesis the air handling unit model is adapted to a basement case but pros and cons with basement versus top floor is further discussed in chapter 3.

1.4 Method

This work is divided in to three parts:

- A model that represents the optimal air handling plant room and how it relates to the total airflow and the Specific Fan Power and an analysis where comparing the results with an existing building.
- Data extraction from existing office buildings where areas for technical systems, gross external area, SFP, shaft area, airflow etc. are documented.
- Analysis of the total shaft area versus gross external area, where a key performance indicator is extracted as percent total shaft area per gross external area.
- With this indicator, two office scenarios are performed. On Varying Air Volume case and one chilled beam case. The results from this is analysed with an economic perspective.

The first part consists of analysing the air handling plant room to create a theoretical model of it. This was done by studying literature, essays that cover air handling unit techniques and documents and drawings from existing buildings.
After the study, a general model for air handling plant rooms was created with the constraint to only depend on the unit's geometry, i.e. the model is solely depending on the height, width and length of the air handling unit. This helps to process large amounts of data since the input data is the dimensions for several air handling units, which results in a graph depending on total airflow and SFP level.
The theoretical air handling plant room model is verified with the help of the second part, where a measurement study of existing office buildings was conducted.

In the second part, data is also extracted to lay the basis for the analysis in the third part, where the total shaft area is compared to the gross external area. This is performed by plotting the shaft area against the gross external area and use a trend line to receive a Key Performance Indicator “key numbers”, which is used in part four.

1.5 Report structure

The introduction chapter 1 provides the background, purpose and the limitations of the current study. The description of the methodology is included.

In chapter 2, a review of the technologies related to the study is provided, with a general constraints declaration for the other technical areas and more specific information for the air handling unit’s equipment. Other related parameters used in this thesis are defined here.

The work method for the air handling plant room model and the two theoretical ventilation scenarios for office buildings are described in chapter 3.

Chapter 4 provides a description of the observation made from the results of the air handling plant room model for all three heat exchanger types.
The results are analysed and presented in chapter 5, where measured office buildings are compared to the model as a demonstration. Also the study of the total shaft area in office buildings compared to the gross external area is evaluated, followed closely by the two theoretical ventilation of office building cases.

The discussion and conclusion of the work are reviewed in chapter 6.

2. Construction & components

This chapter defines the terms used and what the different technical systems are and what they cover.

2.1 Air handling plant room

An air handling plant room consists of an air handling unit, a shunt group, water and cleaning supplies, a floor drain and at least one cabinet for electricity and control. A layout example is illustrated in Figure 4.

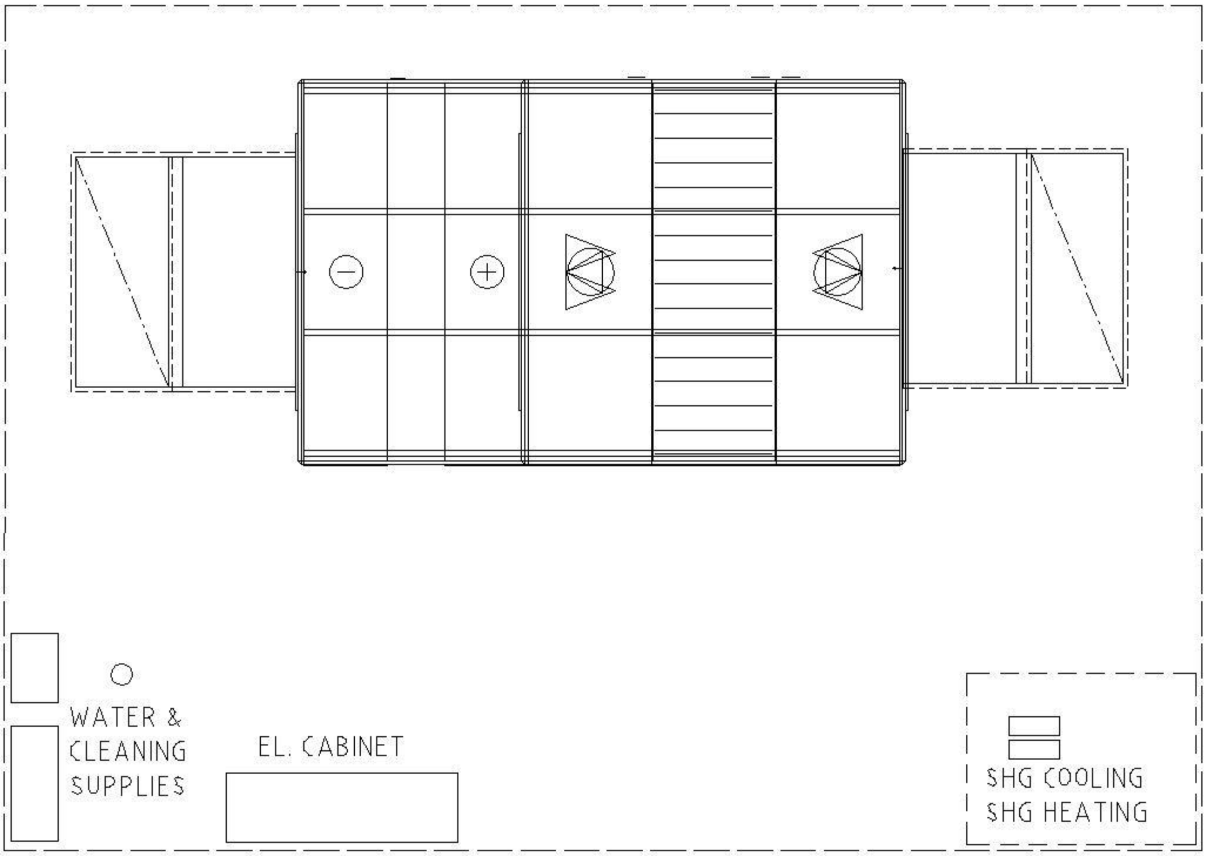


Figure 4. *Layout example of an air handling plant room.*

2.1.1 Air handling unit

The air handling unit regulates and circulates air as part of a heating, ventilation and air conditioning (HVAC) system (ASHRAE, 2008). The air handling unit in this thesis consists of fans, heating and cooling coils, filters, heat exchanger and dampers. Silencers are installed after the AHU in the ducts either as a bent silencer or a conventional straight silencer. The basic setup used in this thesis can be seen in Figure 5 but with varying type of heat exchanger.

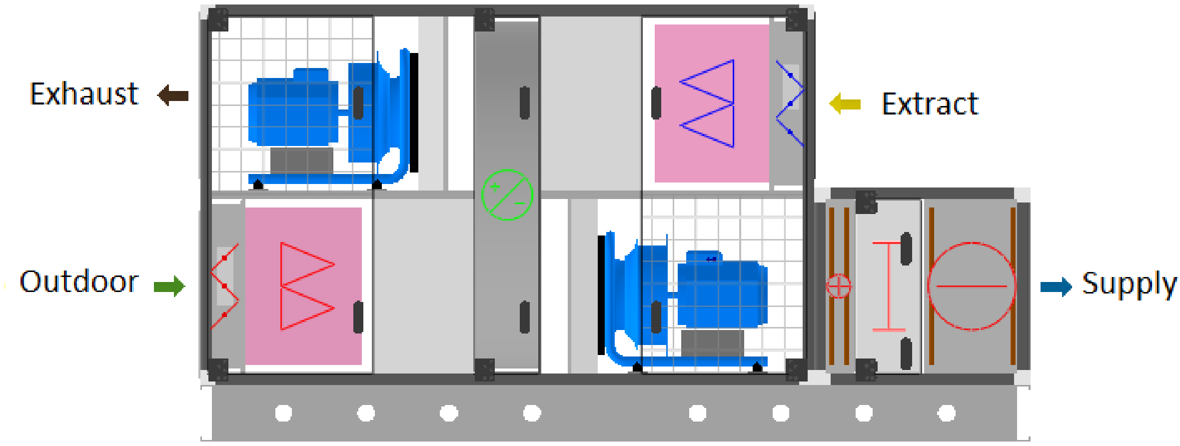


Figure 5. *Sectional view of an air handling unit with rotary heat exchanger.*

The equipment in the lower section of the air handling unit shown in Figure 5, from left to right (outdoor to supply) is: damper, filter, rotary heat exchanger, fan, heating coil and cooling coil.

The path through the lower section is starting with outdoor air supplied from a clean zone, usually from roof-level. From the intake it is transported to the air handling unit through a duct dimensioned for a designed pressure drop, in this thesis it is 50 Pa. Upon arriving to the unit the air first passes the damper and then the air filter where particles are removed. In this case, heat is recovered in a rotary heat exchanger which is described in detail further on page 9. The fan is located after the heat recovery unit and it drives the air due to an increased pressure. If the air temperature after the fan is lower than the design supply temperature the air is heated when passing through the heating coil or if it is higher, it is cooled in the cooling coil. After the air handling unit, the air proceeds through ducts, with a, in this thesis, design pressure drop of 180 Pa to an air supply device and supplied to the room.

The equipment in the upper section of the air handling unit shown in Figure 5, from right to left (extract to exhaust) is: damper, filter, heat exchanger and fan.
The air path starts with air being extracted and transported from the room to the damper with a design pressure drop of 180 Pa in this thesis. After the damper the air is filtered and heat is recovered in the heat recovery unit. After the last component, the fan, the air is transported out of the building with a pressure drop set to 50 Pa.

2.1.2 Shunt group

A shunt group is the link between a primary and secondary system in waterborne heating and cooling systems, e.g. between the district heating heat exchanger (primary circuit) and heating coil (secondary circuit) (Shunt AB, 2003).
The secondary system often works at different temperatures and flows than the primary system. The shunt unit is mounted between these two and mixing media (primary / secondary) in a controlled way with a control valve and actuator to get the correct temperature of the secondary system. The circulation pump ensures that the correct flow circulates in the secondary system.

2.1.3 Ventilation

The air handling unit consists of equipment that suits the specific building activity and the equipment used in this thesis can be seen in Figure 6 below. Below there will be a short introduction of the different equipment and how these influence the outcome of this study. Both heating and cooling coils require a heating/cooling central and shunts groups but important to note is that in this thesis only the shunt groups are considered with respect to area.

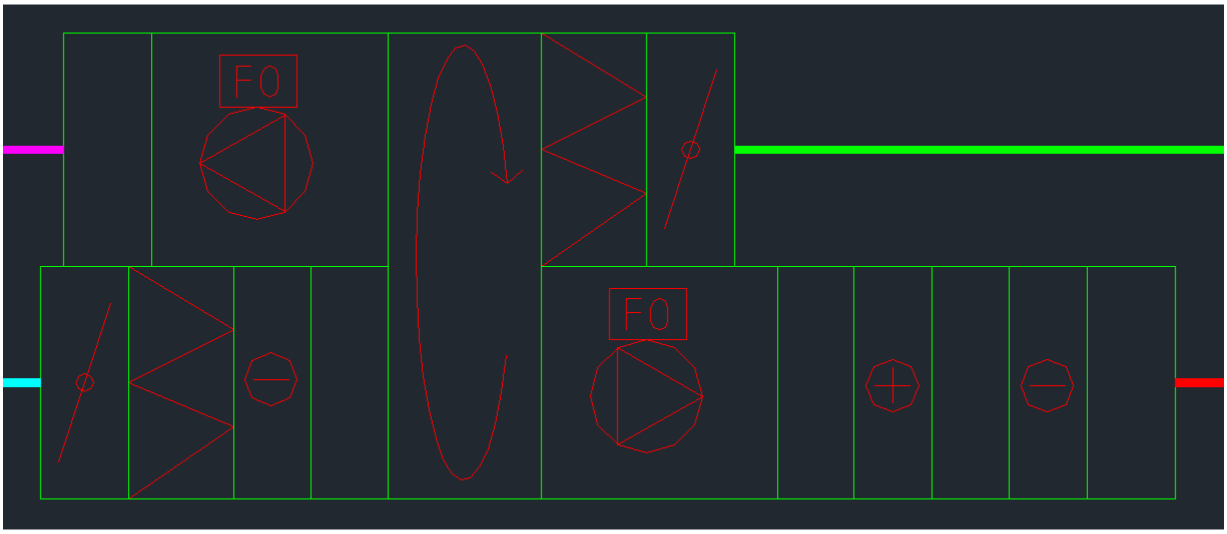


Figure 6. *Schematic example of a rotary heat exchanger air handling unit containing the equipment used in this thesis.*

2.1.4 Fans

In an air handling unit there are at least two fans, one fan for the supply air and one for the exhaust air. At high airflow rates two fans can be used in parallel. The purpose of the fan is to compensate for the pressure resistance in the ducts, air devices, dampers and all components in the air handling unit. The choice of fan in an air distribution system depends on several criterions:

- pressure rise
- airflow rate
- available space
- noise criteria
- cost

2.1.4.1 Plug fan

A plug fan is a radial fan with backward curved blades that has no scroll housing, see Figure 7. It is energy effective although it has lower efficiency compared to other fans due to the reduced system effect in interconnecting components (Catarina Warfvinge & Mats Dahlblom, 2010), system effects are further describes on page 12. Plug fans are used in the air handling plant room model and in all buildings measured in this thesis.

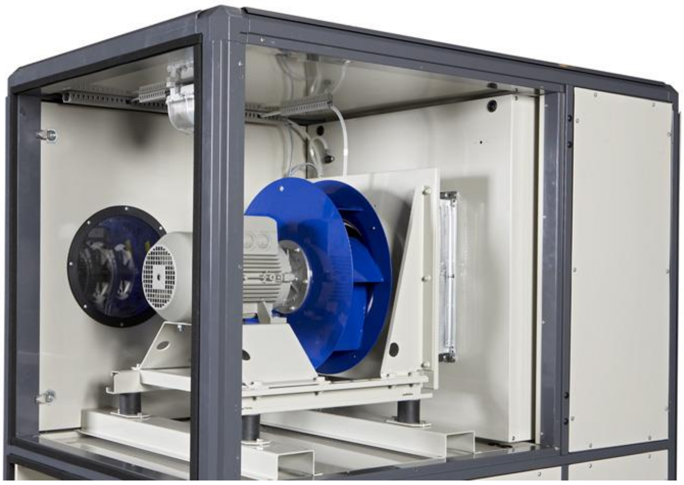


Figure 7. *Plug fan without scroll housing. Source: Dantherm.*

2.1.4.2 Radial fan

A radial fan has scroll housing and can use forward, backward or radial blades to provide a large pressure rise and airflow. The different blade types are illustrated in Figure 8. The main disadvantage with radial fans is that they have large system effect losses if the duct design deviates from optimal (International Energy Agency). Radial fans are more common in special cases. (International Energy Agency)

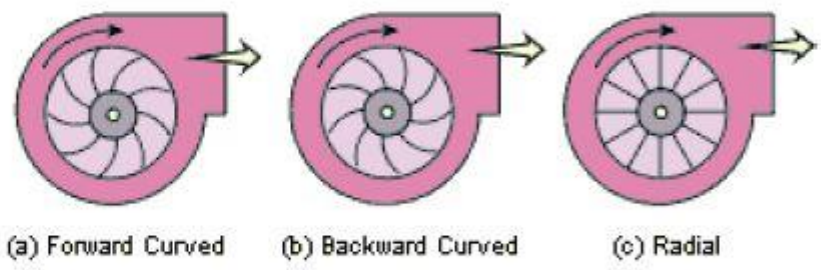


Figure 8. *The different blade types for radial fans. Source: International Energy Agency.*

2.1.5 Heat exchanger

The heat exchangers purpose is to recover heat from the exhaust air and transfer it to the supply air. The choice of heat exchanger type depends on several factors such as (Fläkt Woods):

- Activity in the building
- Risk of air leakage between exhaust and supply air and problems if so happens
- Available Space
- Temperature efficiency

This can be done with different techniques but in this thesis three techniques are applied, rotary, plate and battery heat exchangers.

Lack of functionality in the heat exchanger by reduced recovery efficiency implies an increase in energy use. Also it might lead to an unachievable supply temperature at low outdoor temperature. The definition of temperature efficiency η_t is shown in equation 1:

$$\eta_t = \frac{t_2 - t_1}{t_3 - t_1} \tag{1}$$

Where $t_1 = \text{ }temperature\ outside\ air\ before\ the\ HX$ [°C]

$$t_2 = \ temperature\ outside\ air\ after\ the\ HX\ [°C]$$
$$t_3 = \ temperature\ inside\ air\ before\ the\ HX\ [°C]$$

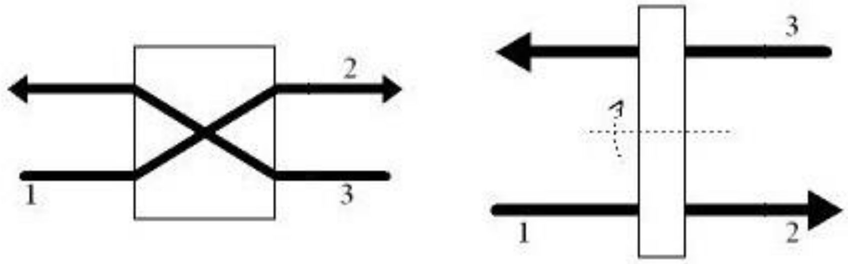


Figure 9. *Plate heat exchanger (left) and rotary heat exchanger (right). Source: Engineering Tool Box.*

2.1.5.1 Rotary heat exchanger

A rotary heat exchanger consists of an impeller with several small holes. Extracted air heats (or cools) the material of the wheel when the impeller rotates, this heat is transferred to the outdoor air when the heated part of the wheel rotates and comes in contact with the outdoor air components. The pressure drop over a rotary heat exchanger is relatively low, around 100 Pa (Catarina Warfvinge & Mats Dahlblom, 2010).

The advantage of rotary heat exchangers:

+ High temperature efficiency
+ Low pressure drop
+ Can be used as cool recovery during summer

And disadvantages are:

- Risk for leakage containing contaminants and odour between exhaust and supply air
- Moving parts, creates the risk of error
- Outdoor air and exhaust air ducts must connect to the same room

When using a RHX, both latent and sensible heat may be transferred between extract and supply air, the latent heat is transferred when moisture in the outlet air condensates on the wheel. When using a hygroscopic wheel the moisture itself can transfer to the supply air side otherwise the water is drained out.

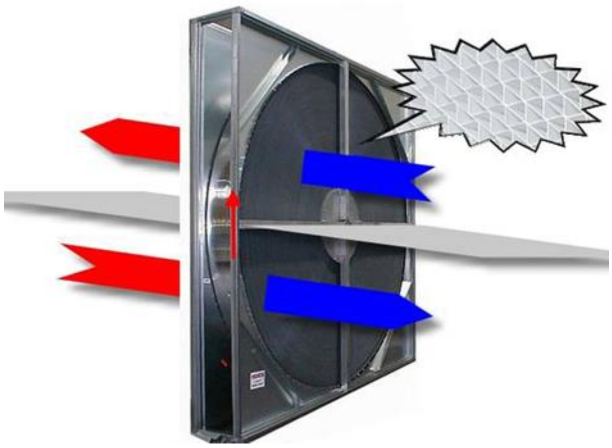


Figure 10. *Rotary heat exchanger. Source Rotorindustry.*

2.1.5.2 Cross flow heat exchanger

A cross flow heat exchanger is constructed of thin parallel metal plates with high conduction ability. Between the laminas, warm and cold air passes alternating and so heat is transferred. The pressure drop over a plate heat exchanger is approximately 150 Pa (Catarina Warfvinge & Mats Dahlblom, 2010).

The advantage of cross flow heat exchangers:

- + Minimal leakage from contaminants and odour between exhaust and supply air
- + No moving parts

And disadvantages are:

- – Low temperature efficiency
- – High pressure drop relative rotating heat exchanger
- – Outdoor air and exhaust air ducts must connect to the same room

Both latent and sensible heat may be transferred in this heat exchanger also but no moisture since there is no contact between the flows.

2.1.5.3 Battery heat exchanger

A battery heat exchanger consists of two air batteries connected with a fluidized circuit. One of the batteries is placed on the supply side and the other on the exhaust side, between these there is water circulated by a pump. The water is heated by the exhaust air and cooled by the supply air. This technique makes it possible to separate the exhaust unit from the supply and put them next to each other if room height is limiting or put the supply unit in the basement and the exhaust unit on the top floor. The previous installation gives low pressure drop since less ducts are required. In this thesis they are used next to each other where they share service area. The battery heat exchanger has the highest pressure drop of all heat exchanger mentioned in this thesis and it is approximately 200 Pa (Catarina Warfvinge & Mats Dahlblom, 2010).

The advantage of battery heat exchangers:

- + No leakage from contaminants and odour between exhaust and supply air
- + Can separate exhaust and supply unit
- + The recovered heat can be used for other purposes as well

And disadvantages are:

- – Low temperature efficiency
- – High pressure drop on the air side relative other solutions
- – Require circulation pump which consumes energy

2.1.6 Filter

Outdoor air contains particles, gas and vapour. The size vary from 0.01 µm to about 100 µm, in comparison with a rain droplet, which has a diameter of 1000 µm., Filters used for comfort ventilation are most commonly used to remove particles and not gases from the air. Filters also make sure that ducts and components do not corrode or gets soiled. The pressure drop over the filter depends on the filter class and velocity of the air going through.
In this case filter class F7 is used both for supply and exhaust, it has an initial pressure drop of 50-100 Pa and a final pressure drop of 200-250 Pa (Catarina Warfvinge & Mats Dahlblom, 2010).

2.1.7 Damper

In an AHU the intake dampers main functions is to enable the air intake to close when the fans are off to prevent outdoor air entering the unit and cause heat losses and cooling damages. When the fans are disabled there is a risk of indoor air going back in to the ventilation ducts. Dampers in air handling units are also used to isolate the unit if there is smoke development and redirect this through a smoke extraction fan that can be installed in parallel with air handler (Catarina Warfvinge & Mats Dahlblom, 2010).

2.1.8 Heating coil

At low outdoor temperatures the heat exchanger is not sufficient to reach the desired supply air temperature. Then a heating coil is used to heat the supply air the remaining temperature. The pressure drop over the heating coil is roughly 40 Pa (Catarina Warfvinge & Mats Dahlblom, 2010) but depends on the size of the coil and the air velocity going through. A heating coil is illustrated in Figure 11.

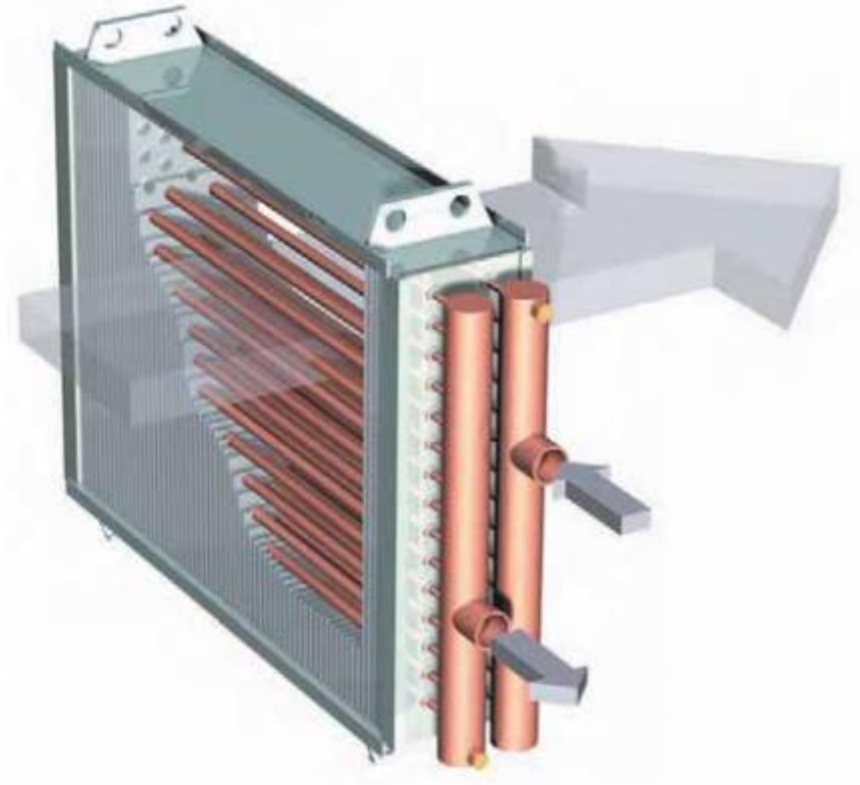


Figure 11. *Lamina heat exchanger. Source: Fläkt Woods.*

2.1.9 Cooling coil

The cooling coil has the same construction principle as the heating coil but the temperature difference between air and water is lower, thus it requires more heat transfer area. This results in a higher pressure drop of around 60 Pa (Catarina Warfvinge & Mats Dahlblom, 2010).

2.1.10 System effects

The system effects considered in this thesis is the pressure drop due to unfavourable duct design after a fans outlet. This is caused from high air velocity and asymmetry in the velocity profile. When entering a bend shortly after the fan outlet system effects arises (Fläkt Woods). Although this is not the case when using plug fans with backward curved blades and no scroll housing since the distribution pattern is fully developed almost directly after the fan outlet, see Figure 12.

This is partly why this thesis only considers plug fans and not centrifugal fan but also due to that the market is plug fan dominated. Centrifugal fans require more duct distance after the air handling unit (Lennart Jagemar & Mattias Larsson, 2000) due to its distribution pattern as seen below in Figure 13.

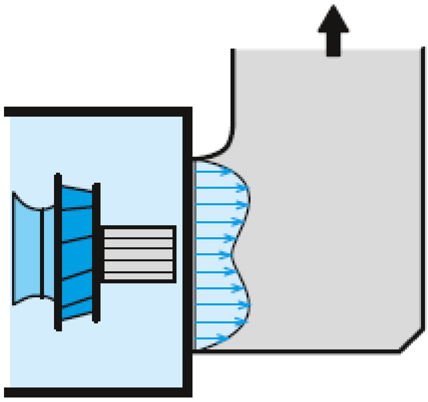


Figure 12. *Distribution pattern plug fan. Source Swegon.*

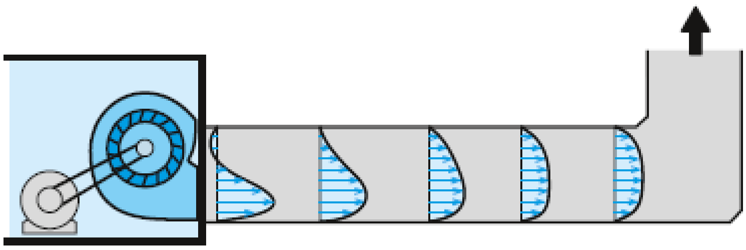


Figure 13. *Distribution pattern centrifugal fan. Source Swegon.*

2.2 Heating central

District heating or a heat pump is examples of heat sources that are commonly used in office buildings and its job is to transfer heat and supply hot water to the building.

2.2.1 District heating

District heating is a method for large scale heat production and transportation. The heat is produced in a centralized production facility with the possibility of advanced emission treatment. The supply temperature in the Nordic grid is between 90 and 120 °C and the equipment required in a district heating central can be divided in three sections: District heating circuit (primary side), heating circuit (secondary) and the hot water system. Each of these require certain equipment which occupies a certain space, the equipment that requires most space are heat exchanger (there can be one for hot water production and one for heating), pumps, filter, shunts, storage tanks, expansion and mixing vessels. The district heating rooms space requirements are planned with regard to a good working environment and possibilities for maintenance of the equipment (Svensk Fjärrvärme, 2014).

2.2.2 Heat pump

There are three common heat pumps; air source heat pump, geothermal heat pump and exhaust air heat pumps. The basic principal for heat pumps is to move heat from one location to another and these three options impacts the space required for a building differently.

An air source heat pump transfers heat from the outside of a build to the inside or the other way around which makes it a heating system in winter and a cooling system in summer.

When using an air source heat pump it requires an outdoor unit with a shaft to the heating central.

A geothermal heat pump has the same principle as the air source heat pump except it uses the temperature in the ground that is less fluctuating around the year than the ambient temperature which provides a more efficient operating condition. The space requirement for a geothermal heat pump is somewhat different since it requires boreholes that provide around 35 W/m of hole (normal KPI value in Gothenburg). It is expensive to drill enough holes to provide heat during the peak demand which is why often around 50-70 % of peak power is covered, thus this technique is commonly supplemented with either district heating or direct electric heating.

An exhaust air heat pump uses the heat in the exhaust air to heat water that is used for either hot water or heating. This heat pump cannot be used as primary heat source contrary the other two heat pumps since it only reduces the losses and does not add heat. Space demands for exhaust air pumps depends mostly on heat recovery batteries that can be either installed separately in the each air handling unit or use one large battery that is connected to several air handling units with pipes.

2.3 Cooling central

District cooling or a heat pump is two common techniques used in office buildings and its purpose is to cool the room.
District cooling works in a similar way as district heating but here the supply water temperature is around 6 °C and the heat pumps provides a lower temperature of water instead.

2.4 Sprinkler central

A sprinkler system is an active fire protection measure consisting of a water supply system, which provides enough pressure and flow to the water distribution piping system. In a sprinkler central the service line is connected to the building, the supply water can go directly to the water distribution piping system or to fill a storage tank that is then pumped. Depending on how high the building is or how large flow is needed, it may require pressure rise pumps, the number of pumps also depends on how many and how large sections the building is divided in to. In the sprinkler central there is also a cabinet that controls the pumps unless it is integrated in the sprinkler pump unit HI-FOG).

2.5 Switchgear central

In this thesis guidelines are for switchgear centrals with maximum 1000 V AC or 1500 V DC and follow the references in SS 436 21 01. Switchgear central is a space intended for electrical switchgear where access is limited. There is a requirement that emergency doors should be at least 2 m high and 0.75 m wide and should open outwards with a minimum ceiling height of 2 m in the room. The room should be placed so it is easily accessible without affecting the environment through noise or magnetic fields. When planning and designing the switchgear room is done it should be taken into account that the equipment can be assembled, installed, operated and maintained without danger. In addition to space for operation and maintenance, the escape route room design with a limitation of maximum 20 m to the exit is decisive. When the equipment is installed there should be at least 1200 mm free space in front of it, called back-up distance, or 1500 mm when installations on opposite walls is done as in the illustration in Figure 14. In the case of smaller switchgear equipment installations this distance can be reduced to 800 mm (Svensk standard SS 436 21 01).
With these standards and guidelines the room gets a certain geometry illustrated in Figure 14.

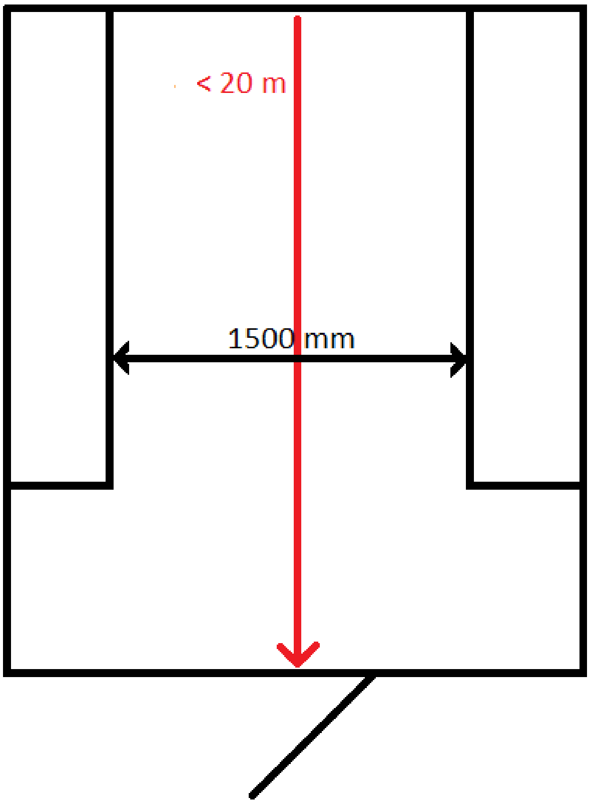


Figure 14. *Typical layout in a switchgear central.*

2.6 Tele and data central

Tele and data centrals can be a separate room or part of the electrical room. The electrical room is defined as a room or place, other than the switchgear central, designed for electrical switchgear where other common equipment can be placed (Svensk standard SS 436 21 01). The same regulations regarding the work environment is applied in this area as for the switchgear central but the difference here is the reduced need for back-up distance since the chock risk is eliminated.

2.7 Key performance indicator

Key performance indicator, KPI, reflects the goal of an organization, i.e. it is used to evaluate factors that are crucial for an organization. KPIs are used to assess progress toward a defined goal; in this thesis KPI evaluates the volumetric airflow per square meter air handling plant room or room height with respect to SFP. In other words, optimize the air handling plant room area depending on the airflow.

In this thesis, KPIs are used illustrating the share of total shaft area in relation to the gross external area and as a tool to create different scenarios.

2.8 Specific Fan Power

Specific Fan Power (SPF) is used to quantify the energy-efficiency of a system where a fan is creating motion of air. SFP is the electric power needed for the fans in relation to the amount of air that is put to motion (International Energy Agency). The SFP value is not constant; it varies with the flow rate and the fan pressure rise and is measured as follows:

$$SFP = \frac{\sum P_{fan}}{q_v}$$

Where
$\sum P_{fan}$ = The sum of all fan powers [kW]
q_v = The design airflow rate, the greatest of supply or exhaust airflow rate [m^3/s]
If the system is unbalanced, i.e. supply air is larger or smaller than exhaust air, q_v is the largest of them.
Equation 2 shows a dimensional analysis where it is shown that SFP can be expressed in units of pressure, which is a measure of energy per volume of air.

$$[SFP] = \frac{kW}{\frac{m^3}{s}} = \frac{\frac{kJ}{s}}{\frac{m^3}{s}} = \frac{kJ}{m^3} = kPa \quad (2)$$

Then the relationship between SFP, fan system efficiency and fan pressure rise can be expressed according to equation 3.

$$SFP \cdot \eta_{tot} = \Delta P_{tot} \quad (3)$$

Where
ΔP_{tot} = Total fan pressure rise [kPa]
η_{tot} = The overall efficiency of the fan system [0<η_{tot}<1]

This means that if SFP is to be decreased preferably the overall efficiency should increase and the total fan pressure rise should decrease, i.e. the total pressure drop in the air distribution system and/or in the air handling unit should be decreased.

The total fan pressure rise can be expressed as:

$$\Delta P_{rise} = \Delta P_s + \Delta P_b + \Delta P_{AHU} + \Delta P_{system} + \Delta P_{dampers} + \Delta P_{device} \quad (4)$$

Where $\Delta P_s = pressure\ drop\ in\ straight\ ducts\ [Pa]$
$\Delta P_b = pressure\ drop\ in\ bends\ [Pa]$
$\Delta P_{AHU} = pressure\ drop\ in\ air\ handling\ unit\ [Pa]$
$\Delta P_{system} = pressure\ drop\ caused\ by\ system\ effects\ [Pa]$
$\Delta P_{dampers} = pressure\ drop\ in\ dampers\ [Pa]$
$\Delta P_{device} = pressure\ drop\ in\ supply - or\ exhaustdevices\ [Pa]$

In this thesis the pressure drops in the air distribution is set to 180 Pa each for supply and extract air while in exhaust and incoming (outdoor) air it is set to 50 Pa each. This means that the pressure drop in the air handler and overall total efficiency of the fan system is varying to achieve different SFP levels for a specified airflow.

The easiest way to reduce the pressure drop in the air handler is to increase the size (International Energy Agency). By doing this the dynamic pressure drop in filters and air heating/cooling coils etc. are decreased due to a reduced air velocity in the unit since the dynamic pressure depends on the air velocity in square when turbulent flow occurs (Catarina Warfvinge & Mats Dahlblom, 2010). The efficiency of a large fan is slightly increased when compared to a smaller fan due to psychical scaling law (International Energy Agency). The selection of the fan is controlled by the situation on the market, thus in this thesis plug fans have been used.

A VAV system's SFP will be stated at full airflow although the yearly average may be lower since the full airflow sets the dimension for the air handling unit. The measured buildings SFP values are based on the design conditions and not the actual values verified from a time period of measuring.

2.9 Measured buildings characteristics

There are four main building categories, residential, educational, office and hospital buildings. These buildings have different requirements when it comes to HVAC, in general residential buildings have the lowest and hospitals the highest demands. In this thesis a main focus is on office building.

The measured buildings vary from a few floors of a couple of hundred m^2/floor up to 19 floors and 1000 m^2/floor but all with similar interior style, open floor plan with a few individual offices, meeting and conference rooms. Most of the buildings are new but measurements have also been made on reconstructed building, but only if the interior style matched the other buildings. Some of the buildings have a restaurant inside, engineering wise this is often solved with a separate air handling unit for the restaurant area that is equipped with a battery or plate heat exchanger due to the risk of odour spread. In this thesis, the area for each heat exchange technology is measured separately which will result in some degree of uncertainty in the data.

The geometry of the measured office buildings is relatively the same, square and tall except for the occasional building which is round and the majority uses a VAV system. All measured buildings in this thesis have a balanced supply/exhaust airflow which means that the total exhaust air is equal to the total supply air.

2.10 Gross external area

The gross external area (GEA) is defined as the area measured on each floor from outside the external walls and is similar to the Swedish gross area BTA. Here, technical areas are included but not areas like balconies (Lennart Jagemar, 1996).

2.11 Net internal area

The net internal area (NIA) is defined to measure to the inner surface of external walls but excludes auxiliary and ancillary spaces, similar to the Swedish LOA (Lennart Jagemar, 1996).

3. Method

In this chapter the air handling plant room model that is created is described along with the shaft area study and the case study of two office buildings with different ventilation system technique.

3.1 Implementation

In order to measure the space requirements for air handling plants an AHU room model is created and described in the following chapter below. The model is limited to a total supply/exhaust airflow range of 4 – 40 m^3/s and is divided in to four SFP levels. One low energy case with SFP 1.2 kW/(m3/s) that illustrates future energy demands for air handling systems. The next level is SFP 1.5 kW/(m3/s); this is a common value of modern buildings today while the majority of buildings in this thesis are around SFP 2.0 kW/(m3/s) which represents the energy goals a few years back when they were built. The last high-energy case is with SFP 2.5 kW/(m3/s) which represents older buildings or buildings with restricted available space. Important to note here is how VAV systems are defined in chapter 2 since most office building use this technique.

Apart from this there is a set of parameters that is used for designing the air handling units when using the manufacturers' software's, these parameters are presented in table 15.

Table 15. *Input data for software.*

	Supply air	Extract air	Outdoor air	Exhaust air		
Total pressure drop, duct [Pa]	180	180	50	50		
	Heating coil	Cooling coil	DUT [°C]	Outdoor RH [%]	Extract Temp. [°C]	Extract RH [%]
Fluid temp. in [°C]	60	6				
Fluid temp. out [°C]	30	12				
Temp. after the function [°C]	20	16				
Summer			27	60	22	40
Winter			– 18	90	20	40

The goal in this thesis is that there should be at least data from two air handling units from different manufacturers for each airflow and SFP level since different manufacturers construct air handling units differently with respect to height, width and length. Although this is not a conclusive method but it is considered in this thesis to be good enough to create graphs using trend lines. The air handling units are design using software provided by the manufacturers and for every unit that fulfils the SFP and airflow demands, with the input data in table 15, is used to construct these graphs.

The software's used in this thesis are Systemair's SystemairCAD, Swegon's ProUnit and IV Produkt's IV Designer. There are of course several other manufacturers but these three were chosen for this thesis.
Data is documented from the software and then compiled, sorted according to airflow and SFP in an excel document. Roughly 100 rotary, 50 plate and 50 battery heat exchangers was created.

3.2 Air handling plant room model

In order to go from an air handling unit with height, length and width given, to how large the plant room needs to be, a room model is required. The model is designed to use the least possible space, which implies that a shaft exists where most suitable and no large ducts crossings for the design is needed.
Measurements of the air handling plant rooms were conducted on existing buildings to account for duct crossings and smoke extraction fans that are not included in the optimized model. This study indicated that this could be satisfied by adding 25% to the total area and is plotted in the graphs as an upper limit when conditions are not optimal.

There are two air handling plant room models, the first model represents rotary and plate heat exchanger units since they have the same structure when it comes to inlets, outlets and how to exhaust section is located relative the supply, i.e. on top of each other. Illustrations of this can be seen in Figure 16 and 17.

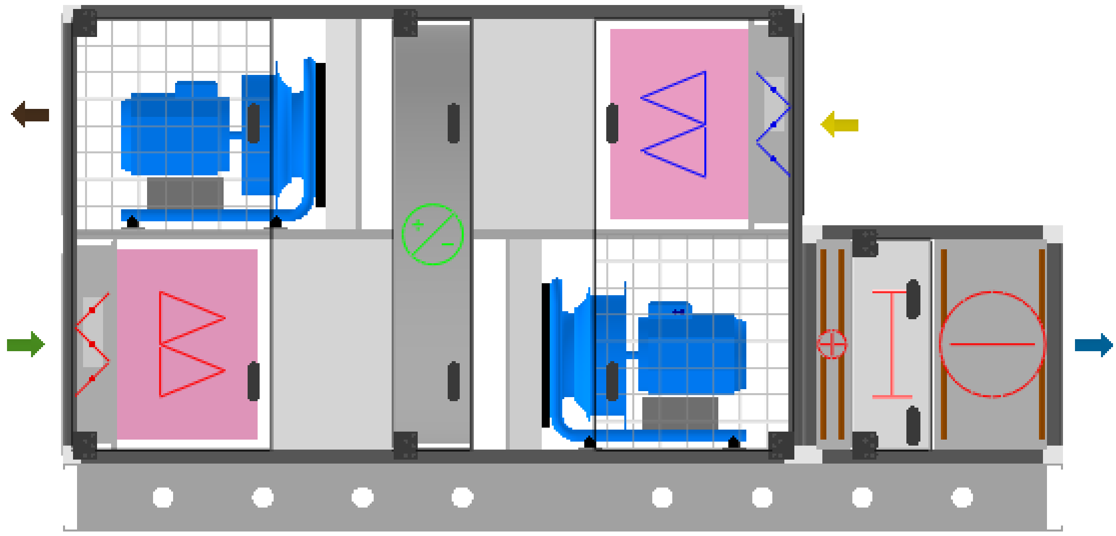


Figure 16. *Rotary heat exchanger.*

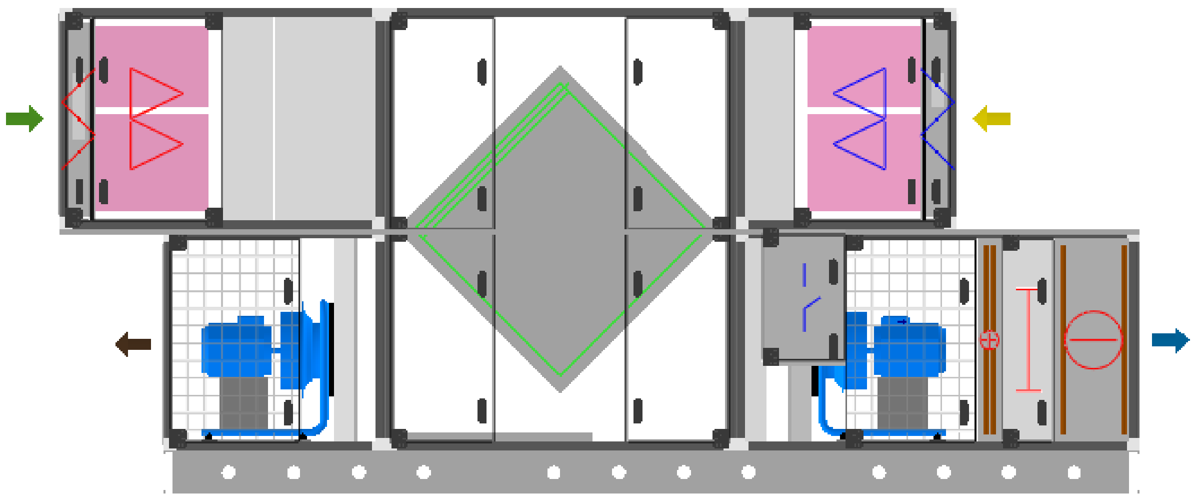


Figure 17. *Plate heat exchanger.*

The other model represents battery heat exchanger units, these have a different model since the exhaust section (top) can be placed next to (or further away from) the supply section (bottom). In this model they are placed next to each other, sharing their service area. This solution leads to a lower overall height of the room.

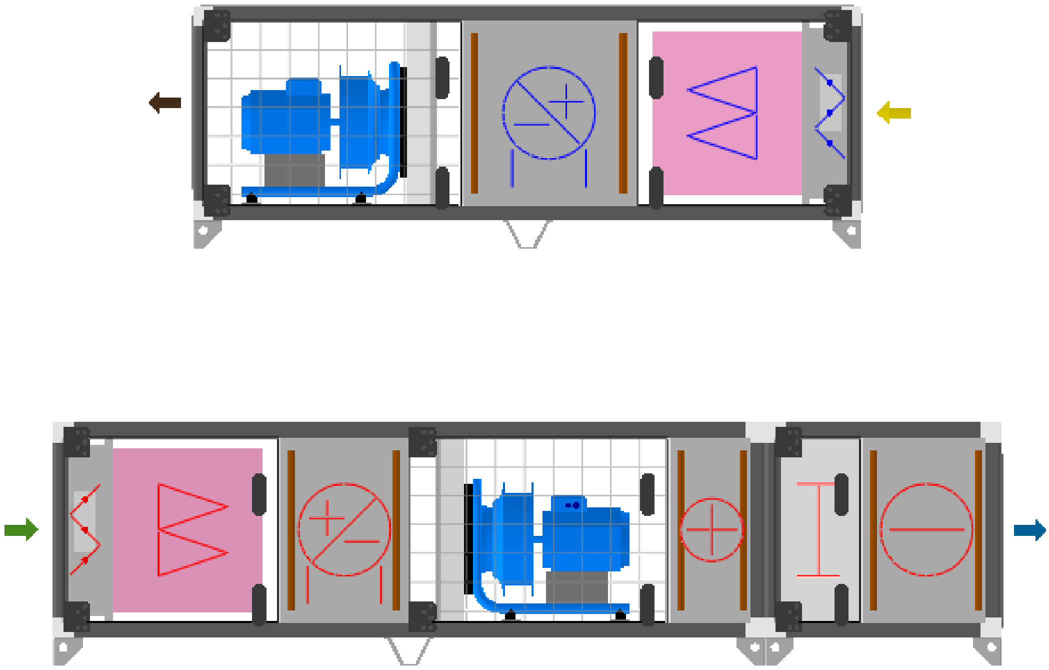


Figure 18. *Battery heat exchanger.*

The general assumptions for this model are based on literature[1], real case studies and from discussions with experienced engineers. These assumptions are stated below:

- The air handling plant room model is quadrangle
- The plant room is solely depending on the geometry of the air handling unit
- The space required for ventilation pipes on both sides of the unit depends on the height and width of the unit
- 600 mm free passage around the unit
- Number of shafts, area and location requirements are met
- Water supply, slop, shunt group and electrical cabinet are integrated according to Figure 19
- Two maintenance area cases
  - 1 x unit width (see Figure 19)
  - 1.5 x unit width (see Figure 20)
- Temperature efficiency of the heat exchange is allowed to vary in order to ease the data collection from air handling units
- All units are equipped with a plug fan with backward curved blades and without scroll housing
- Four SFP levels

[1] Rätt arbetsmiljö för VVS-montörer och driftpersonal

    - 1.2 kW/(m3/s)
    - 1.5 kW/(m3/s)
    - 2.0 kW/(m3/s)
    - 2.5 kW/(m3/s)
- The required ceiling height is calculated as AHU height + 400 mm in order to make room for water pipes passage
- Dampers are installed at outdoor air inlets and extract air inlets
- Smoke extraction fans fits in the room
- There is a limited number of air handling units and manufacturers used to make the graphs
- The model is the same for all three heat exchangers

Thus it is only the floor area that is modelled and the height of the room is depending on the height of the air handling unit chosen.
There are two service cases, small and large; the small service area is seen in Figure 19 and the large service area in Figure 20. With regard to the risk of repetition only rotary heat exchanger is modelled with the large service area. The small service area case origins from AHU manufacturers and the large from old standard advice for HVAC technicians, the service area is used for maintenance and replacing worn equipment. The model includes the standard equipment found in an air handling plant room; there is an air handling unit, water supply, cleaning supplies, electrical cabinet and shunt groups for the heating and cooling. The equipment is integrated in the space required for maintenance and is illustrated in Figure 19.

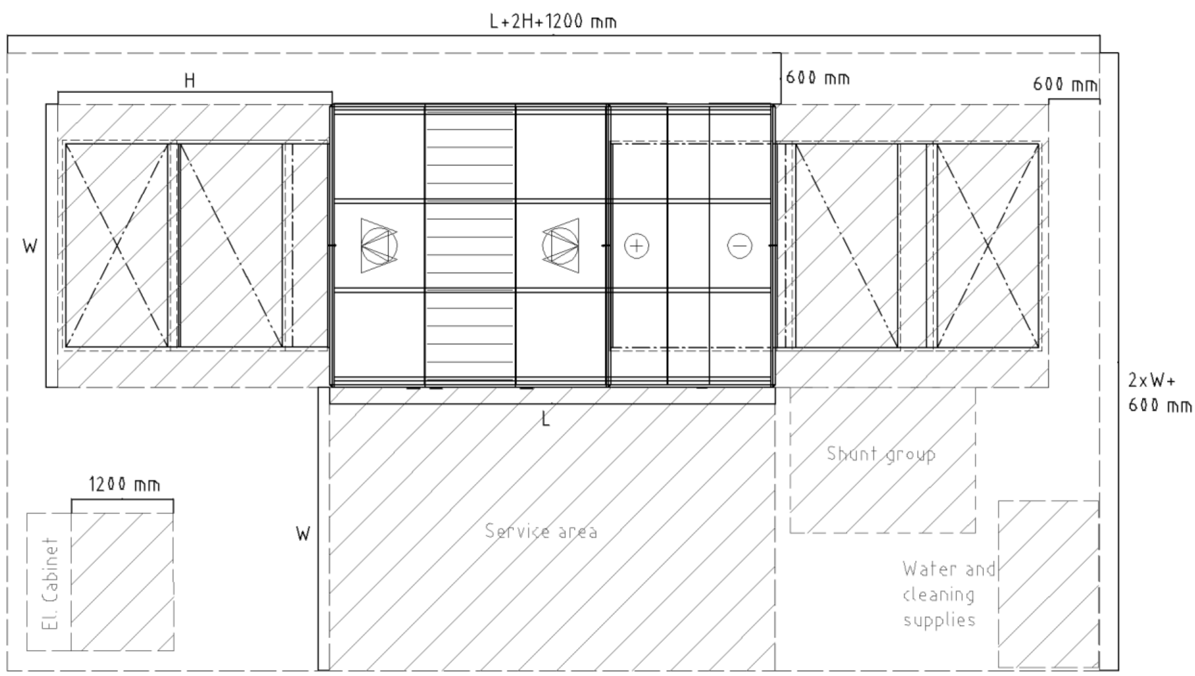


Figure 19. *Small service area with the model dimensions and equipment with service area displayed in the checked area.*

The checked area on both sides of the AHU represents the space required for the ducts to rise and reach a minimum height of 2100 mm, which is the minimum height needed to be called workspace according to Swedish Work Environment Authority and thus can be used for other purposes. The assumption is that the length of the duct going from the unit is equal to the height of the unit. This assumption is only applicable when plug fans with backward curved blades and no scroll housing are used due to the reduced system effects when bends occur short after the unit (See Figure 12) compared to other fans.

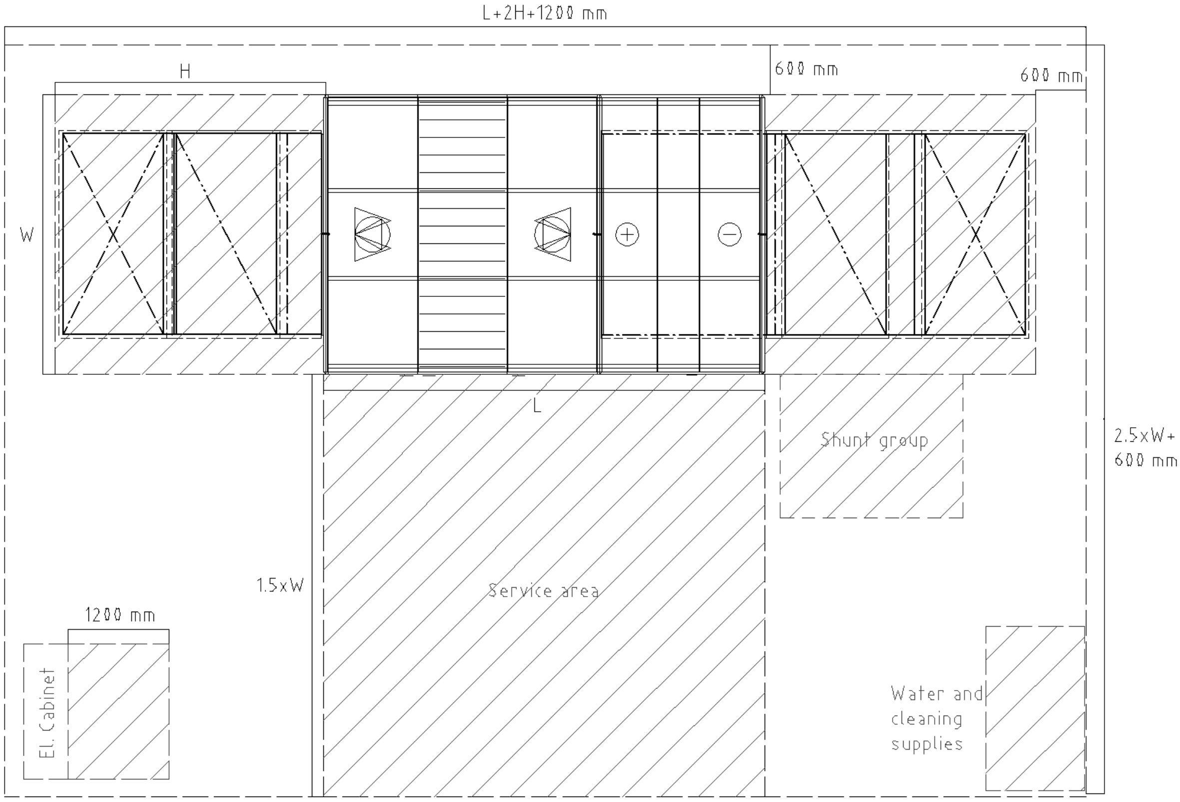


Figure 20. Large service area with the model dimensions and equipment with service area displayed in the checked area. The large service area is 1.5 times the width of the unit which is a common recommendation found in guidelines for HVAC engineers with respect to maintenance etc.

3.2.1 Scaling up AHU room model

When the total airflow rate increases it is common to use one or more air handling units, thus, in this thesis there are two models, one unit and two units. The idea is that the models can be added for any number of units, although this puts extra high demands on shaft locations and the available open space needs to be large. The principle case of four units is illustrated in Figure 22, where the demands on shaft location are obvious, this scenario, however, is not included in this thesis, but the principle is important for large buildings.
Two important assumptions are that the shaft location does not require large duct crossings and that the geometry of the room is quadrangular.

When using two units the air handling plant room model share the same service area of two smaller units, see Figure 21.

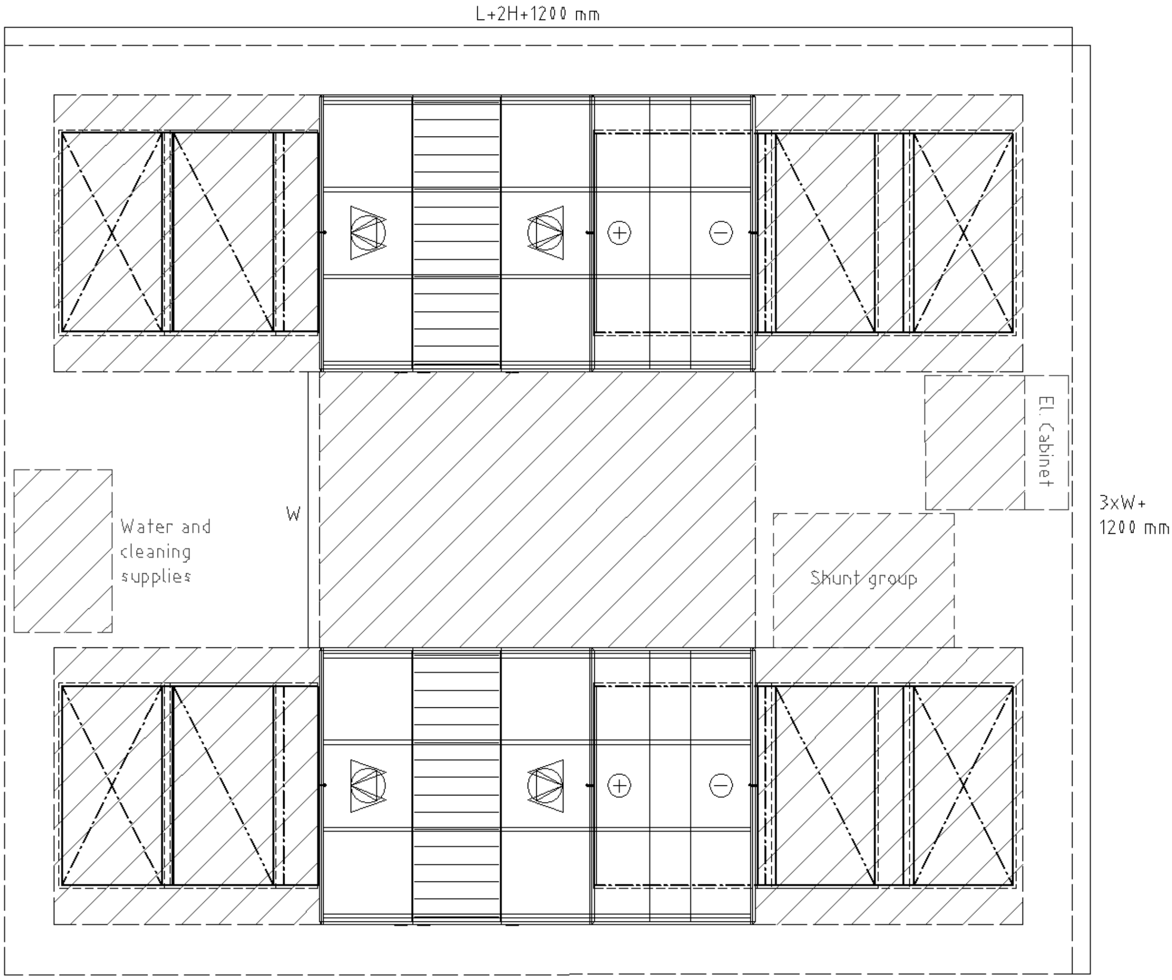


Figure 21. *Small service area for two units with the models outer dimensions and equipment with service area displayed in the checked area.*

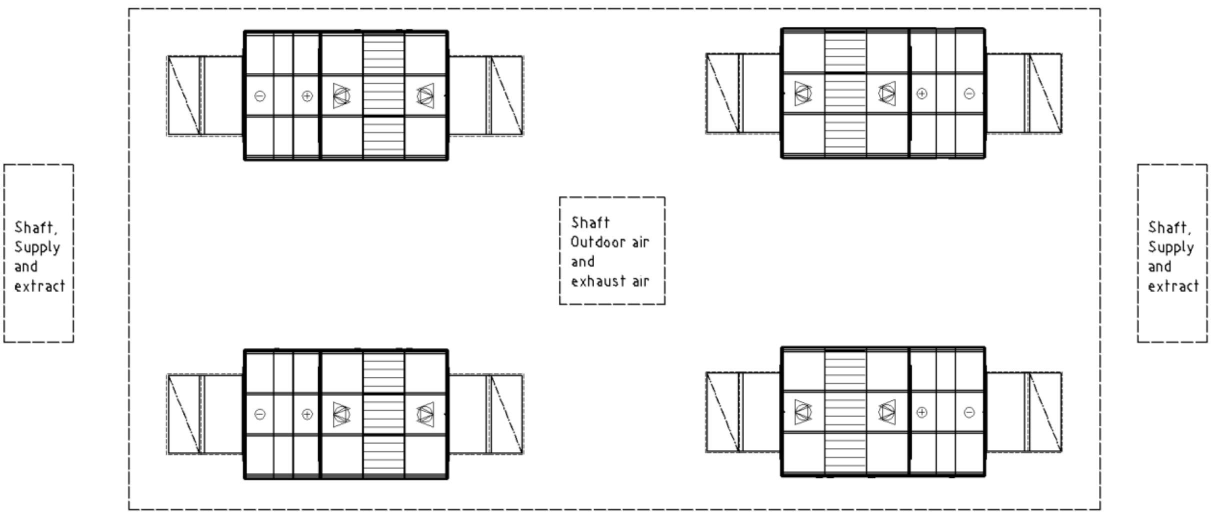


Figure 22. *Layout example of four units with good shaft location available.*

3.3 AHU placement

Depending on where in the building the AHU is located there is different advantages and disadvantages. What could be considered is the amount of ducts required and that different parts of buildings are valued differently. The basement level or ground level is often cheaper

per square meter than the top floor level, but the top floor in turn requires less ducts and shafts since outdoor air and exhaust air is directly connected to the roof or walls. The possibility for having exhaust outlets at ground level depends on the risk for odour spread, noise level and the acceptance of the surrounding environment.

3.3.1 Basement placement

If the AHU is placed in the basement there are two common versions for ductwork. The first case is where both outdoor and exhaust air is supplied and exhausted at the roof level. This is a common scenario and is used when there is risk for any of the stated risks above. The second case, which is used in this model, is when the exhaust air is extracted at ground level and is used when possible due to lower costs. Outdoor air is supplied from where it is most clean which is usually higher up, further away from traffic and not close to chimneys etc.

3.3.2 Top floor placement

With the AHU placed on the top floor, outdoor and exhaust air is directly supplied/extracted from the same level which minimizes the ductwork and the total shaft area, both resulting in reduced costs. Important to note is that it is more expensive to put an AHU room on the top floor.

3.4 Shaft areas – important role in space efficient buildings

The total shaft area in office buildings are measured and used as basis for a theoretical office building where the shaft area is approximated from the existing measured buildings.

What is a shaft? A shaft consists of a vertical distance intended for transportation of air, electricity and water in various forms. It is not just the size of the shaft that is important, but how it is located relative to its destination. Shafts are often located around other vertical distances such as elevators, which often prohibits the optimal, in terms of space, air handling plant room since duct must go unnecessary long distances interfering with the other equipment in the building. This is mostly affecting the air handling plant room due to its large duct dimensions that are difficult to cross without having a high ceiling. If the AHU is placed in the basement, partly below ground, sharing the floor level with parking lots etc., a high ceiling becomes expensive since the ramp that is used to drive in to the parking lot consumes area. One meter of ramp height results in 8-12 meter of ramp length (this is also a fairly common KPI range)[2], thus a high ceiling may save air handling plant room area but cost in ramp area.

In this thesis, it is assumed that the exhaust air is extracted directly at the wall at the end of the unit. The outdoor air has a separate shaft on its side of the unit while the extract and supply air has its own shaft. This design reduces the duct work in the room, thus referred in this thesis to the optimal case.

3.5 VAV vs. Chilled beam scenario

This section describes the assumptions and tools used to create two fictive office buildings with the purpose to enlighten the economic aspect of building various sizes with various SFP levels.

A building ventilated with varying air volume (VAV) is compared to a building with chilled beams with regards to gross external area (GEA). This is to illustrate how the share of the air handling plant room area including total shaft area varies with the gross external area of an

[2] Gunnar Isaksson (Civil engineer, Gicon Installationsledning AB) 2015-05-26

office building. To do this it requires additional data consisting of qualified estimates produced from consulting experienced project engineers with the HVAC sector.
A theoretical building consisting of 700 m^2 (GEA) per floor and with shafts going from the bottom to top level with an assumed airflow of 1.5 l/s,m_{NIA}^2 + 30% for the chilled beams and 2.5 l/s, m_{NIA}^2 + 30% for the VAV system. The size of the shafts is set by the KPI value from measured buildings, see Figure 37, where the shaft area has been measured and related to the gross external area. In this thesis, this value is defined as $KPI_{shaft} = \frac{A_{shaft}}{A_{GFA}}$, where the slope gives the ratio 2.4 %. In addition to this, it is assumed that 75 % of the gross external area is net internal area, thus a total airflow is known. With these assumptions, the total technical area for a given gross external area, with the air handling plant room model as base, a relation between air handling plant room area including total shaft area and the gross external area can be established.

4. Observations graphs

When plotting the air handling unit data generated from the manufacturers software's with the air handling plant room model for a varying airflow rate and SFP sorted, the results is a graph where interesting observations become obvious. This chapter will present the air handling plant room model graphs and observations are declared at the end of each chapter. The measured office buildings that is analysed throughout this thesis are presented in the last graphs together with the air handling plant room model. An analysis based on the observations is presented in the next chapter. The graphs are sorted depending on heat exchanger type.

The trend lines in grayscale are the results from the AHU room model for several airflow levels. The dots represent all data from every AHU. For illustration purpose, not a correct qualified regression analysis, a polynomial trend line in the order of two is used.

In the graphs that follow in the next chapters there is air handling plant room area on the y-axis and airflow rate on the x-axis with a rotary heat exchanger. This goes for the first four graphs in each section for both the small and the large service area case. And in the last graph the height of the room is displayed on the y-axis. All graphs consist of a compilation of four different SFP levels and indicate how area depends on the SFP value.

4.1 Rotary heat exchanger

For the rotary heat exchanger the small service area case is compared to the large separately for the single unit case and two unit's case.

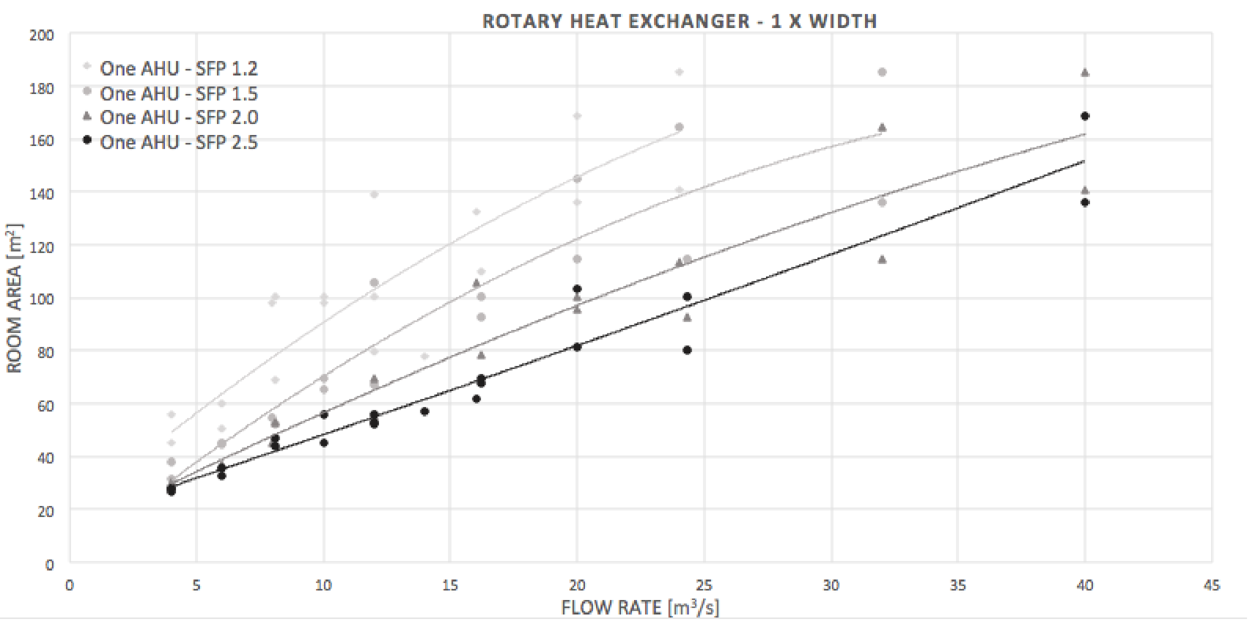


Figure 23. *The optimal air handling plant room area as a function of the total airflow rate for a single air handling unit equipped with a rotary heat exchanger. The service area is one width of the AHU, a.k.a. the small service area case. The trend lines in grayscale indicate the SFP levels.*

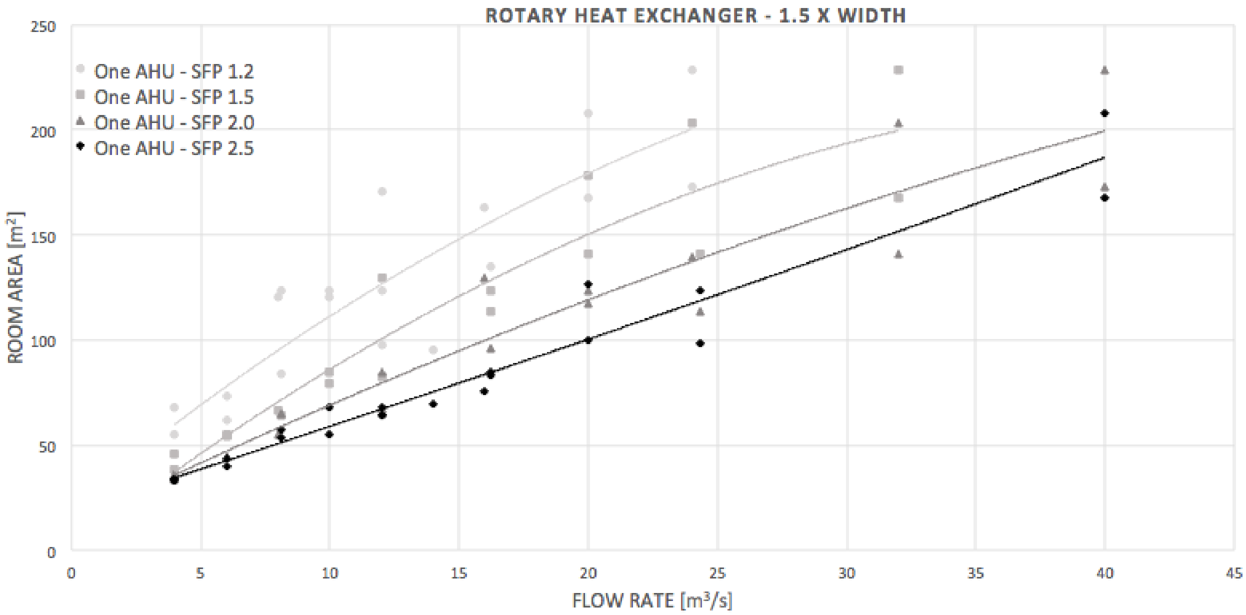


Figure 24. *The optimal air handling plant room area as a function of the total airflow rate for a single air handling unit equipped with a rotary heat exchanger. The service area is one and a half width of the AHU, a.k.a. the large service area case. The trend lines in grayscale indicate the SFP levels.*

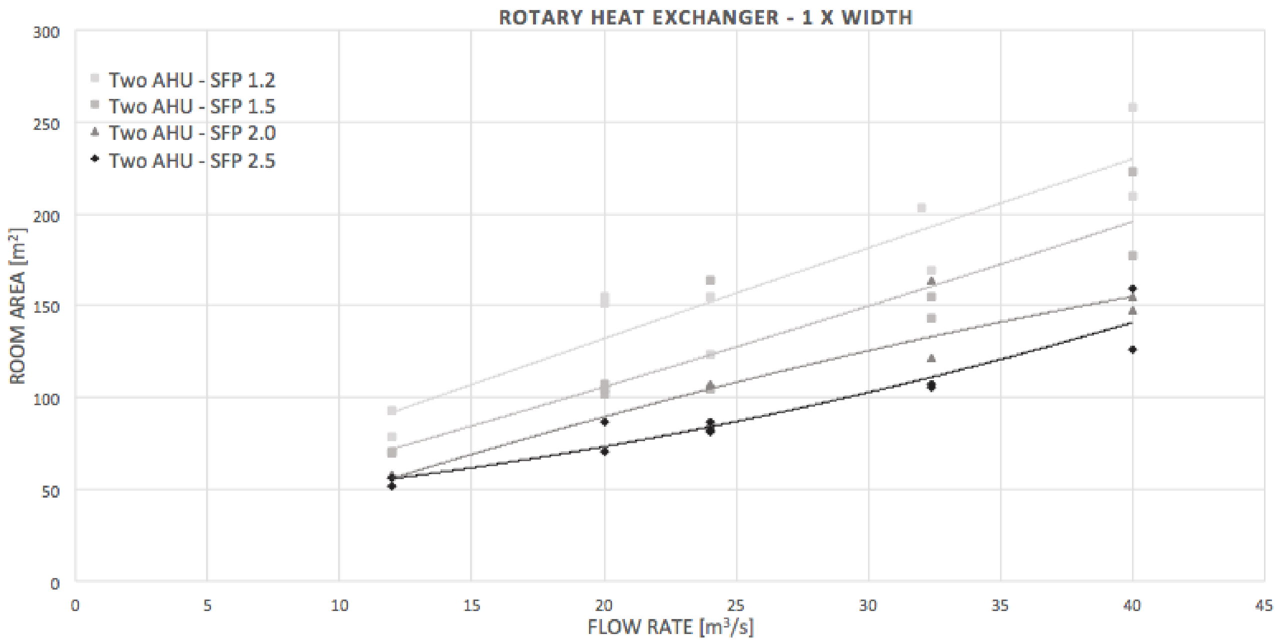


Figure 25. *The optimal air handling plant room area as a function of the total airflow rate for two air handling units equipped with a rotary heat exchanger. The service area is one width of the AHU. The trend lines in grayscale indicate the SFP levels.*

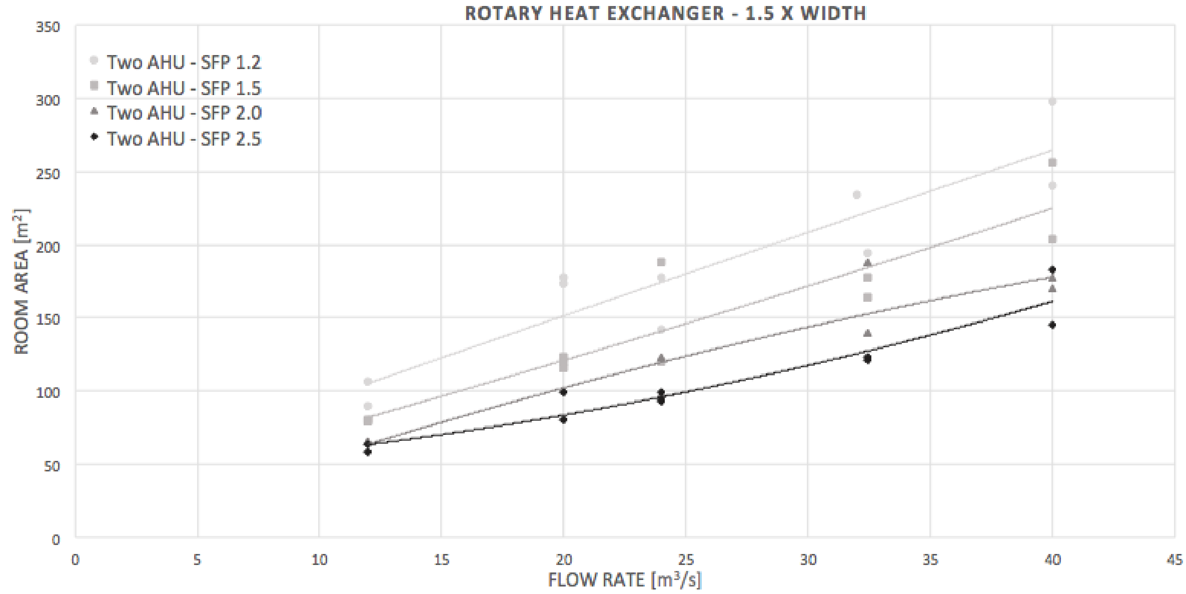


Figure 26. *The optimal air handling plant room area as a function of the total airflow rate for two air handling unit equipped with a rotary heat exchanger. The service area is one and a half width of the AHU. The trend lines in grayscale indicate the SFP levels.*

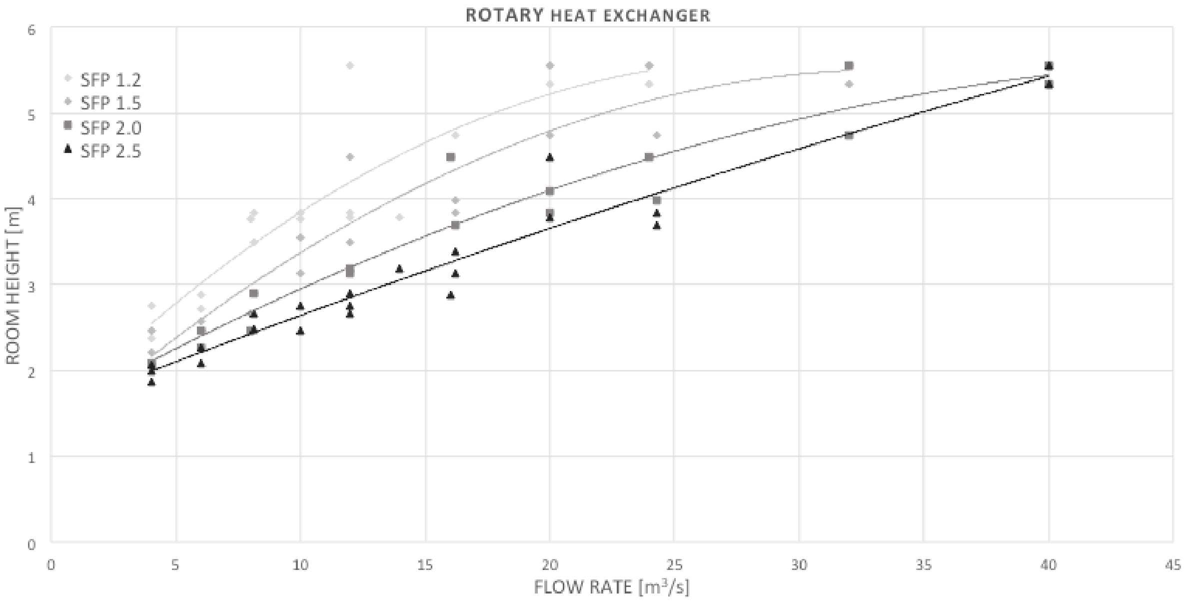


Figure 27. *Air handling plant room height as a function of the total airflow rate for units with rotary heat exchanger. The trend lines in grayscale indicate the SFP levels.*

The first observations are that the lower SFP range, 1.2 kW/(m3/s), requires a larger air handling plant room than higher SFP values. Another observation is how the trend lines relate to each other; they have a similar appearance, to some degree linear, and are almost parallel to each other. This explains the often simplified graphs used in course literature such as Projektering av VVS-installationer [Design of HVAC installations] where a simple linear relation between airflow rate and air handling plant room area are drawn. Although, in this thesis, the impact of SFP level is considered, resulting in a range of air handling plant room areas for a specific airflow. This suggests that SFP value affects the area. The reason why multiple lines start at almost the same spot is due to the scaling effect of air handling units caused by SFP. Thus a total airflow of 4 m^3/s and SFP 1.5-2.5 can be achieved with the same size on the unit but SFP 1.2 requires a slightly larger unit.

The observation to be made in Figure 27, where height versus airflow rate is plotted, is that these heights only depend on the unit's height + 400 mm, which in this case, limited to the software's used, indicates that the tallest rotary heat exchanger is 5.2 m + 0.4 m.
Normally when HVAC engineers design air handling plant rooms the architect provides a ready architectural design with a specified room height that can be substantially lower than the required room heights in this thesis.

The graph in Figure 27 can be used in the following way:
If one has a given ceiling height of 3.5 m and looking for an SFP of 1.2kW/(m3/s), how large is then the largest airflow that can achieve these demands? By reading the y-axis at 3.5 m and follows this until meeting SFP 1.2 line and then reading the x-value to a total supply and exhaust airflow of 9 m^3/s. If more air than this is needed, a second air handling unit must be added.

4.2 Battery heat exchanger

The battery heat exchanger is only modelled for the small service area case and for a single unit case.

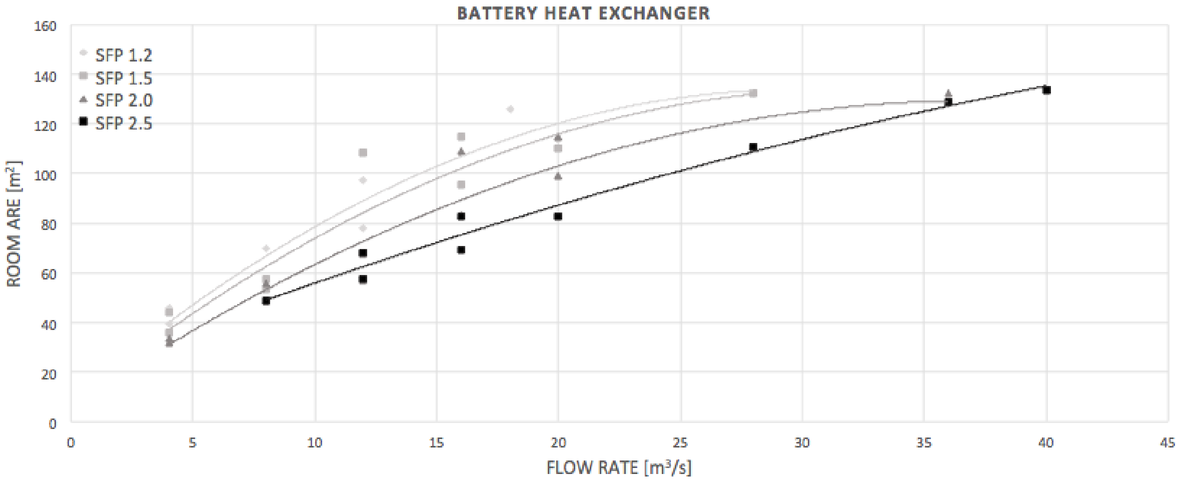


Figure 28. *Optimal air handling plant room area as a function of the total airflow rate for a single air handling unit equipped with battery heat exchanger. The service area is one width of the AHU, a.k.a. the small service area case. The trend lines in grayscale indicate the SFP levels.*

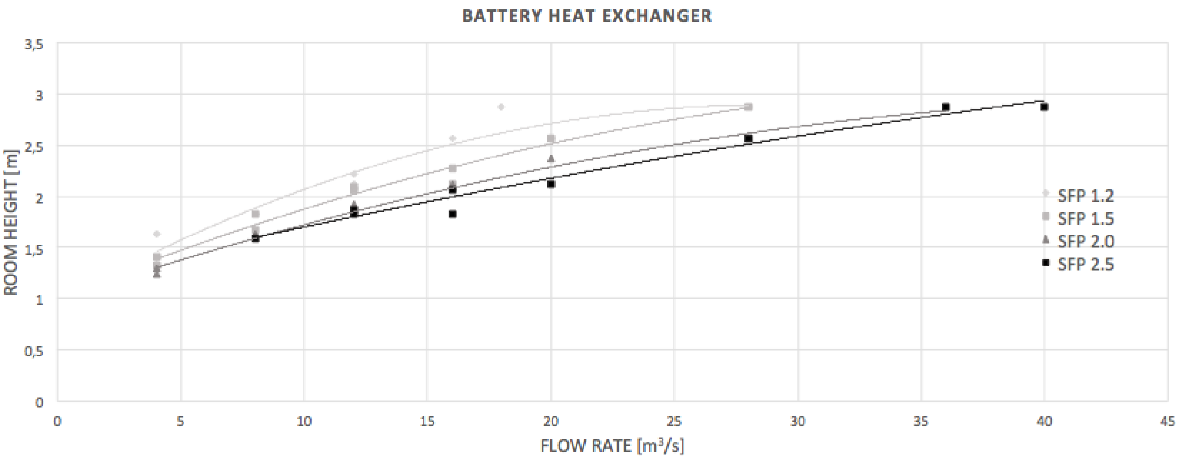


Figure 29. *Air handling plant room height as a function of the total airflow rate for units with battery heat exchanger. The trend lines in grayscale indicate the SFP levels.*

When comparing the room area graphs for the small service area, single unit and rotary heat exchanger with the battery heat exchanger in Figure 28, it is observed that the battery is slightly lower than the rotary. The height graph is the one that separates them most and it is clear, limited to the software's used, that the tallest battery heat exchanger is 2.5 m + 0.4 m.

4.3 Plate heat exchanger

The plate heat exchanger is only modelled for the small service area case and for a single unit case.

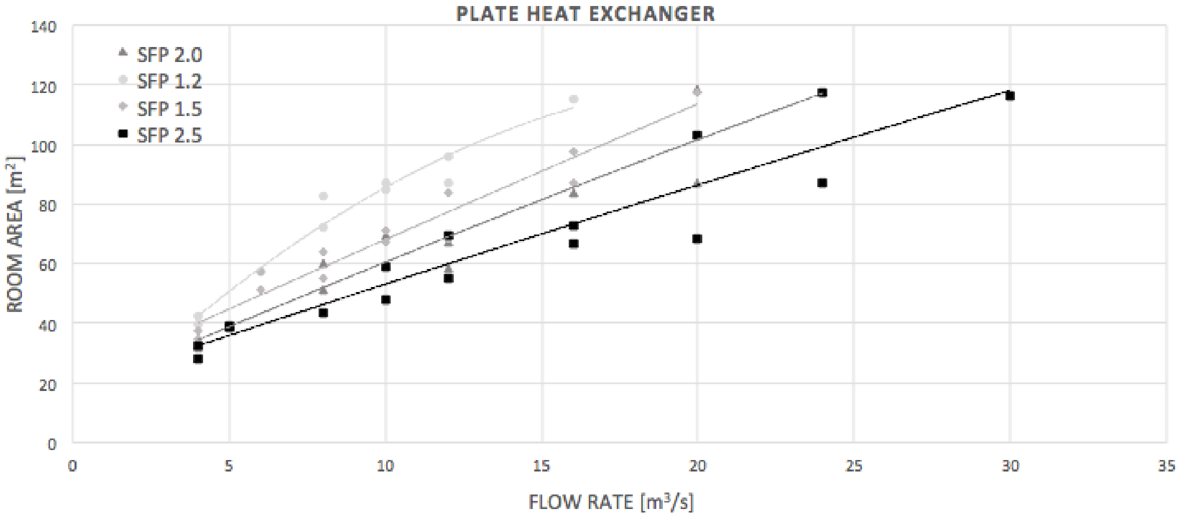


Figure 30. *Optimal air handling plant room area as a function of the total airflow rate for a single air handling unit equipped with plate heat exchanger. The service area is one width of the AHU, a.k.a. the small service area case. The trend lines in grayscale indicate the SFP levels.*

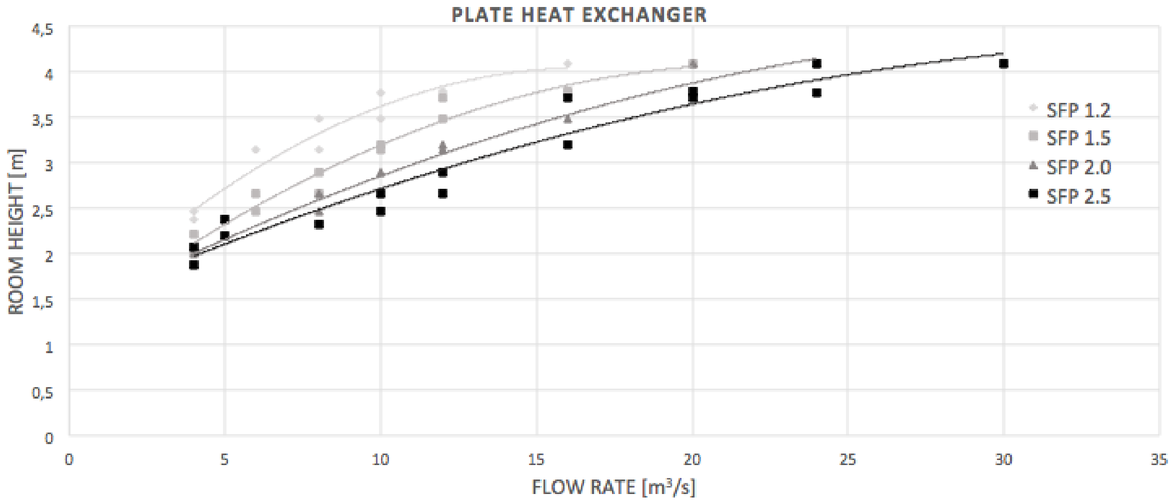


Figure 31. *Air handling plant room height as a function of the total airflow rate for units with plate heat exchanger. The trend lines in grayscale indicate the SFP levels.*

The plate heat exchanger room area graph is very similar to the rotary heat exchanger room are graph. Also here, the biggest difference is how the height graph compares to the other heat exchanger techniques. It is clear, limited to the software's used, that the tallest plate heat exchanger is 3.7 m + 0.6 m.

5. Analysis and evaluation

This chapter presents the measured buildings together with the graphs from the observation chapter and tries to explain what is seen.

5.1 Measured buildings vs. air handling plant room model

In this chapter the air handling plant room models graphs for rotary heat exchangers with the small service area are compared to measured existing buildings, including a second line with 25 % more area to cover for large duct crossings.

In order to make it as easy as possible to identify how the different buildings relate to each SFP value, the graphs in the previous chapter with four SFP values for both single unit and two unit cases will be separated into one SFP value but containing both graphs for single and two units cases.

The measured existing building are plotted in the same graph to evaluate the robustness of the model, a few buildings are discussed and presented at the end of this chapter for the small service area case.

The coloured triangles represent the measured buildings, the SFP and number of units used in the building is specified in the explanation. An example from Figure 32 below, the red triangle consists of a building with two air handling units with a total SFP of 1.6 kW/(m3/s).

The comparison is conducted by first evaluate if a building is limited, according to the model, in height. If limited, what does the room area indicate? Above or below the corresponding SFP line?

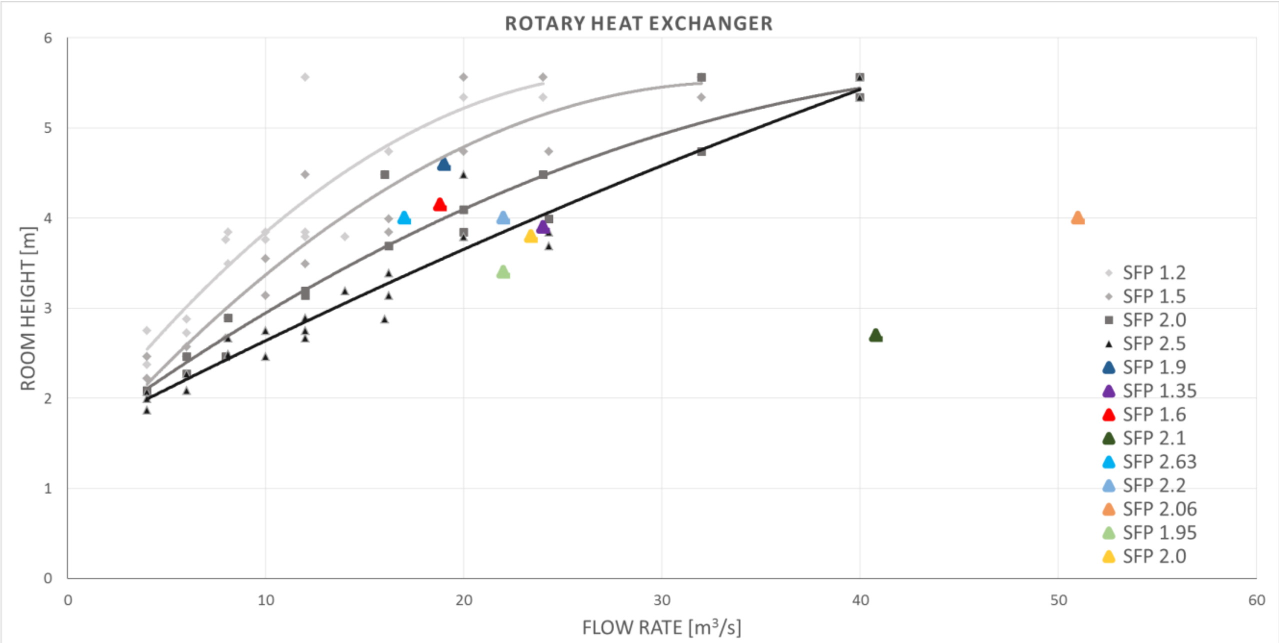


Figure 32. *Air handling plant room height as a function of the total airflow rate for units with rotary heat exchanger. The trend lines in grayscale indicates the SFP levels and all building data used in this thesis is plotted as coloured triangles.*

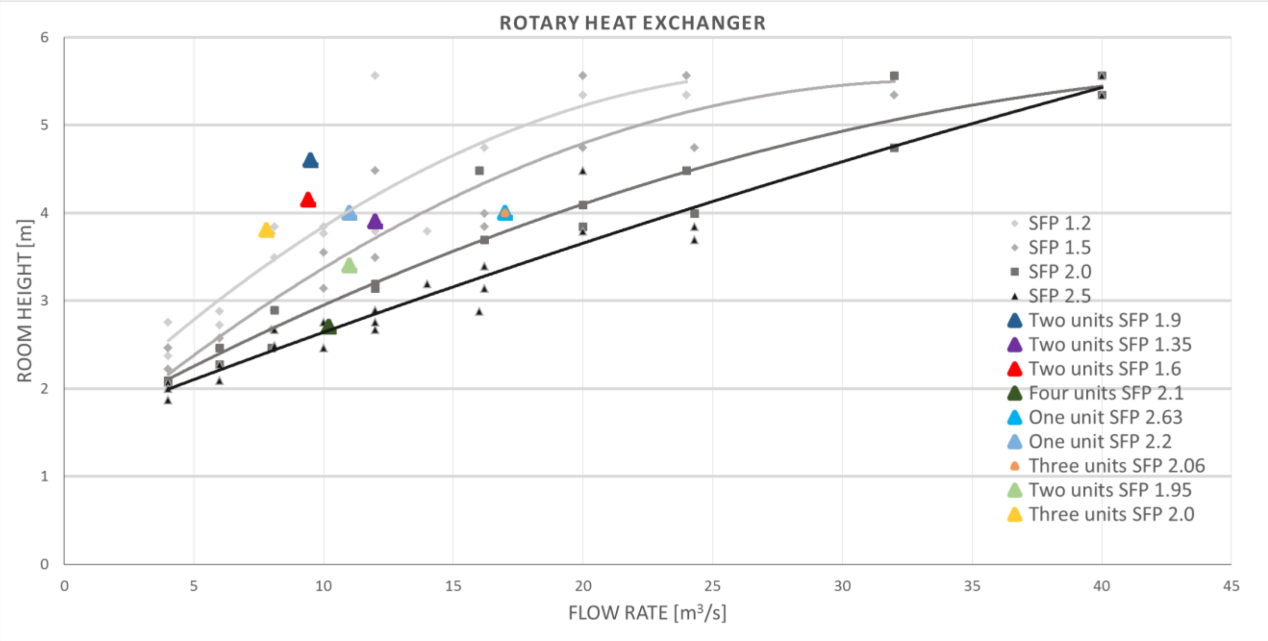


Figure 33. *Air handling plant room height as a function of the total airflow rate for one unit with rotary heat exchanger. The trend lines in grayscale indicates the SFP levels and all building data used in this thesis is plotted as coloured triangles. The "One unit SFP 2.63" is directly located behind the orange building.*

In Figure 32, the measured office buildings are plotted with the total airflow, while in Figure 33, the airflow is divided by the number of units. Thus it is easier to evaluate if the ceiling height is limiting or not. Below is a brief summary of which buildings that is limited or not by the ceiling height.

Table 34. *Summary of Figure 36 describing which buildings are limited, according to the model, by the ceiling height.*

Building	**Limited**	**Not limited**
Dark blue		X
Purple		X
Red		X
Dark green	X	
Blue		X
Light blue		X
Orange		X
Green		X
Yellow		X

Thus, the expected outcome is that the dark green building will require more floor area than what the model indicates is necessary.

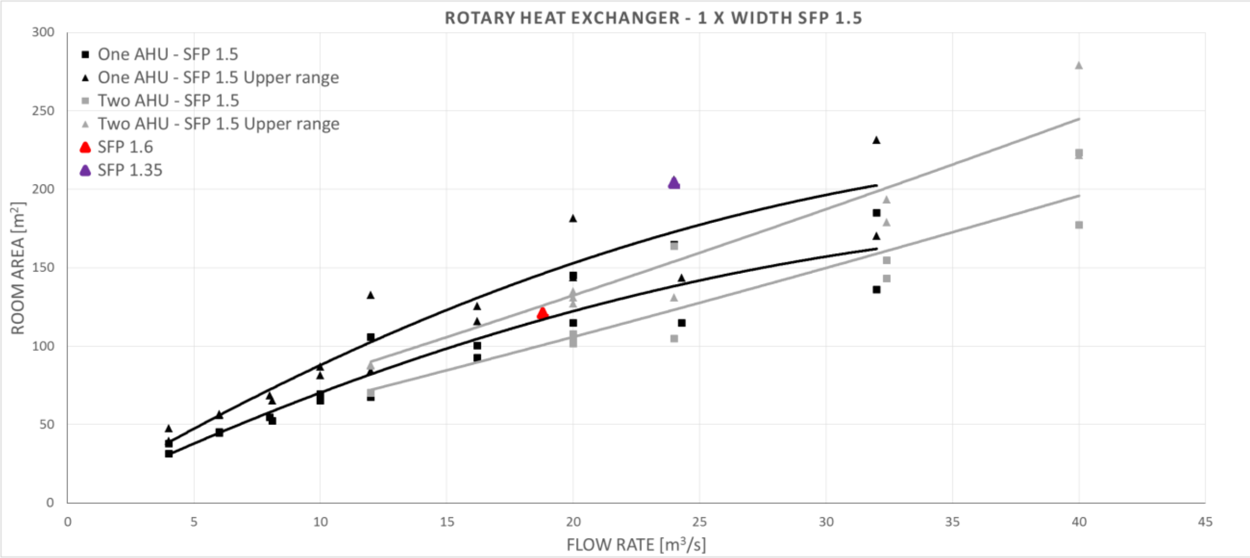


Figure 35. *An air handling plant room model, rotary heat exchanger and SFP of 1.5 kW/(m3/s), plotted together with two buildings represented by a colour and a triangle: Red (SFP 1.6 kW/(m3/s)) and purple (SFP 1.35 kW/(m3/s)). The lower grey line represents the model whilst the upper grey line the model + 25 % area and the lower black line represents the model whilst the upper black line the model + 25 % area.*

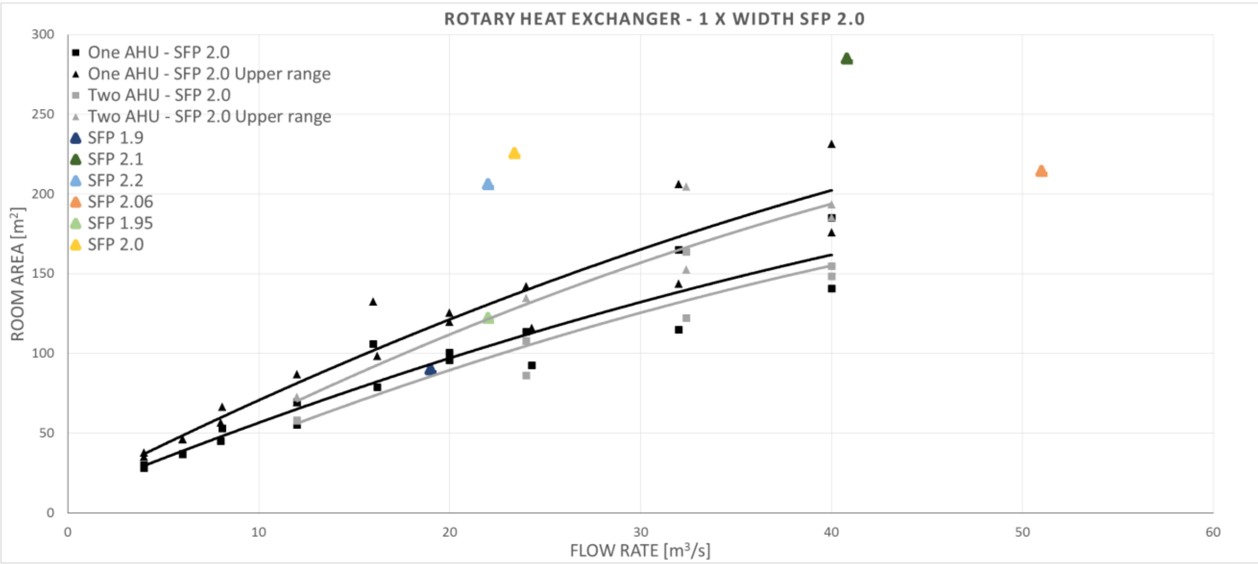


Figure 36. *An air handling plant room model, rotary heat exchanger and SFP of 2.0 kW/(m3/s), plotted together with six buildings represented by a colour and a triangle: Dark blue (SFP 1.9 kW/(m3/s)), light green (SFP 1.95 kW/(m3/s)), light blue (SFP 2.2 kW/(m3/s)), yellow (SFP 2.0 kW/(m3/s)), dark green (SFP 2.1kW/(m3/s)) and beige (SFP 2.06kW/(m3/s)). The lower grey line represents the model whilst the upper grey line the model + 25 % area and the lower black line represents the model whilst the upper black line the model + 25 % area.*

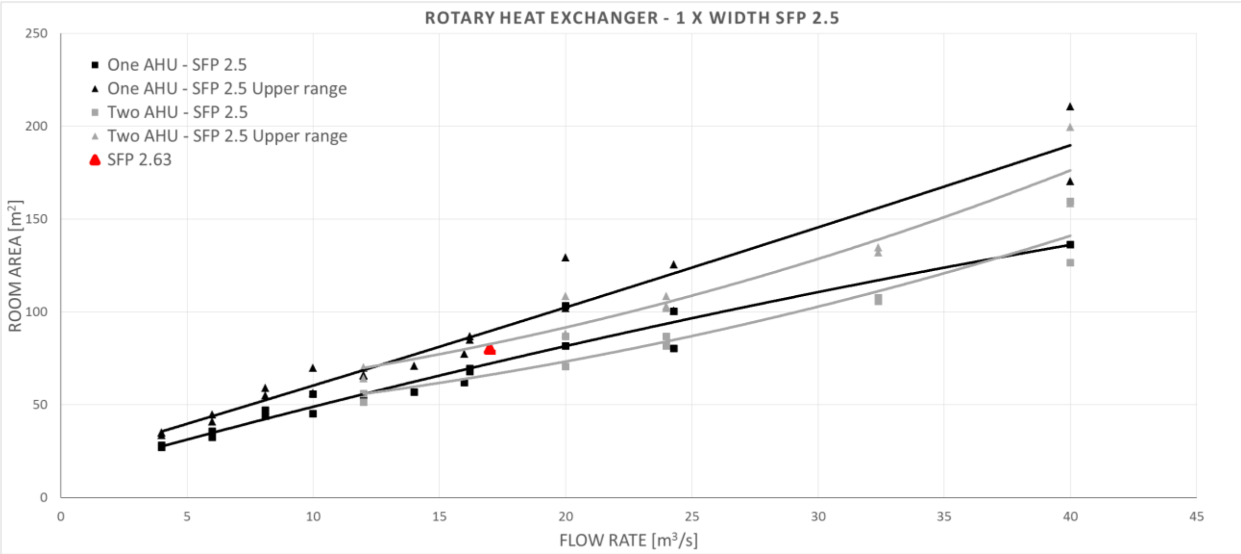


Figure 37. *An air handling plant room model, rotary heat exchanger and SFP of 2.5 kW/(m3/s), plotted together with one building represented by a red triangle with SFP 2.63 kW/(m3/s). The lower grey line represents the model whilst the upper grey line the model + 25 % area and the lower black line represents the model whilst the upper black line the model + 25 % area.*

The red triangle in Figure 35 represents a building with an SFP of 1.6 kW/(m3/s), and as you can see it is in the air handling plant model area range. When looking at the room height in Figure 33, the red triangle shows the actual room height for that building, in this case 4.1 m. The buildings room height is below the SFP 1.5 trend line which means that this is a limiting factor that can increase the total air handling plant room area but in this specific case, two units are placed on the top floor with good shaft placement, i.e. one shaft at each end of the units and there are no large ducts crossing each other. These conditions result in a low room height where its height is basically set to the unit height.

The purple triangle in Figure 35 represents a building with SFP 1.35 kW/(m3/s), and as you can see it is above the air handling plant model area range for SFP 1.5 kW/(m3/s), which is not surprising since it is expected to be between SFP 1.2 and 1.5. The purple building consists of two AHUs but is located in the basement with shafts located on one side of the units, which requires large ducts to cross.

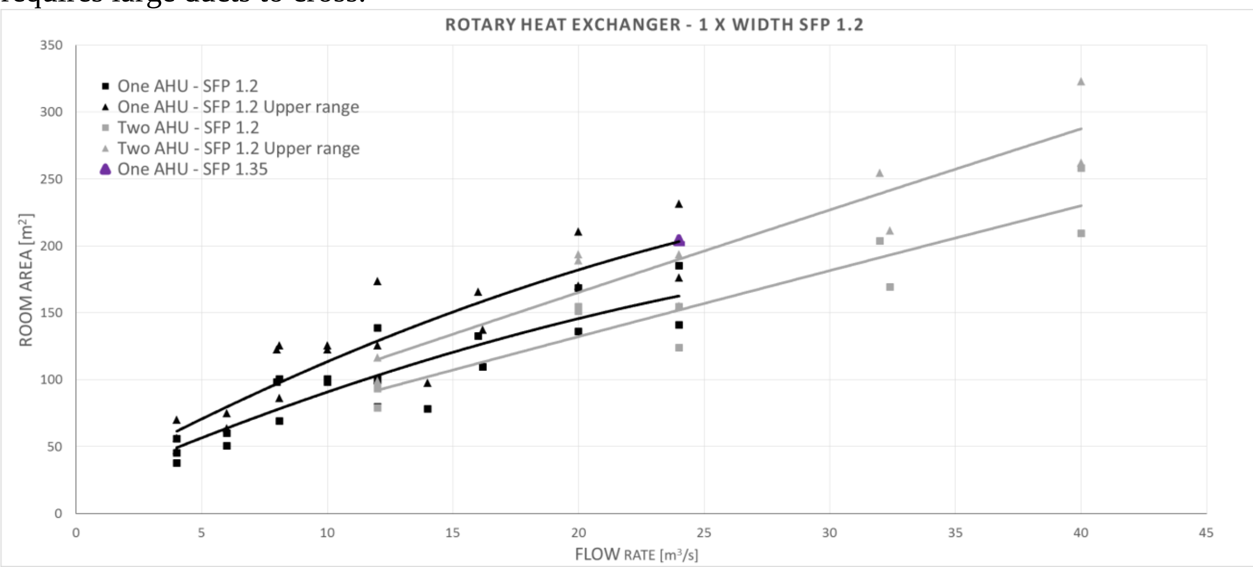


Figure 38. *An air handling plant room model, rotary heat exchanger and SFP of 1.2 kW/(m3/s), plotted together with one buildings represented by a purple triangle (SFP 1.35 kW/(m3/s)), the same building as in Figure 32.*

The lower grey line represents the model whilst the upper grey line the model + 25 % area and the lower black line represents the model whilst the upper black line the model + 25 % area.

When analysing the room height in Figure 33, the purple triangle shows that the actual room height this building is 3.9 m, which is significantly lower than the SFP 1.2 and 1.5 trend line. It is because of this that the purple building ends up in the upper part of the trend line.

The expectations for the dark green building were true but there were two more buildings in Figure 36 that deviated from the model. The light blue and the yellow building also deviated from the model. Why is that? By looking further into these office buildings it becomes clear that they are designed with excessive area surrounding the air handling units and poor conditions when it comes to shaft locations and room geometry.

5.2 Total shaft area vs. GEA

The more shaft area in a building the less leasable area for the landlord. Thus from an economical point of view it is of great interest to reduce the total shaft area. This can be done in many different ways and the share of shaft area varies significantly for different buildings. This is due to many critical conditions:

- The number of floors in a building
- Placement of critical (read high demand in airflow) areas in relation to the air handling plant room and
- If the building has extra shaft area capacity for future flexibility with respect to different tenants

Shaft sizes are often kept constant from the bottom to the top to simplify the construction and create flexibility. The total shaft area depends on the total airflow required in the whole building and this increases with number of floors. This means that the total shaft area in a building is the shaft area for one floor multiplied with number of floors.

By placing highly airflow demanding areas in a tactical part of a building the total shaft area can be reduced. A good example of an unfavourable design is when a large conference room is on the top floor and the air handling plant room is on the bottom floor. This requires a large airflow to be transported through all floors when it is only used on the top floor. A better choice is to place, in the previous scenario, the conference room on the bottom floor which will not require any shafts at all. A third option is to also have the air handling plant room on the top floor and still have the benefit from the reduced shaft area.

When designing HVAC systems in office buildings it is good practice to have reserve capacity in terms of space in the shafts in order to satisfy future tenants with other demands.

The results from the review of the existing buildings are shown in Figure 39, where totals shaft area is on the y-axis and gross external area on the x-axis.

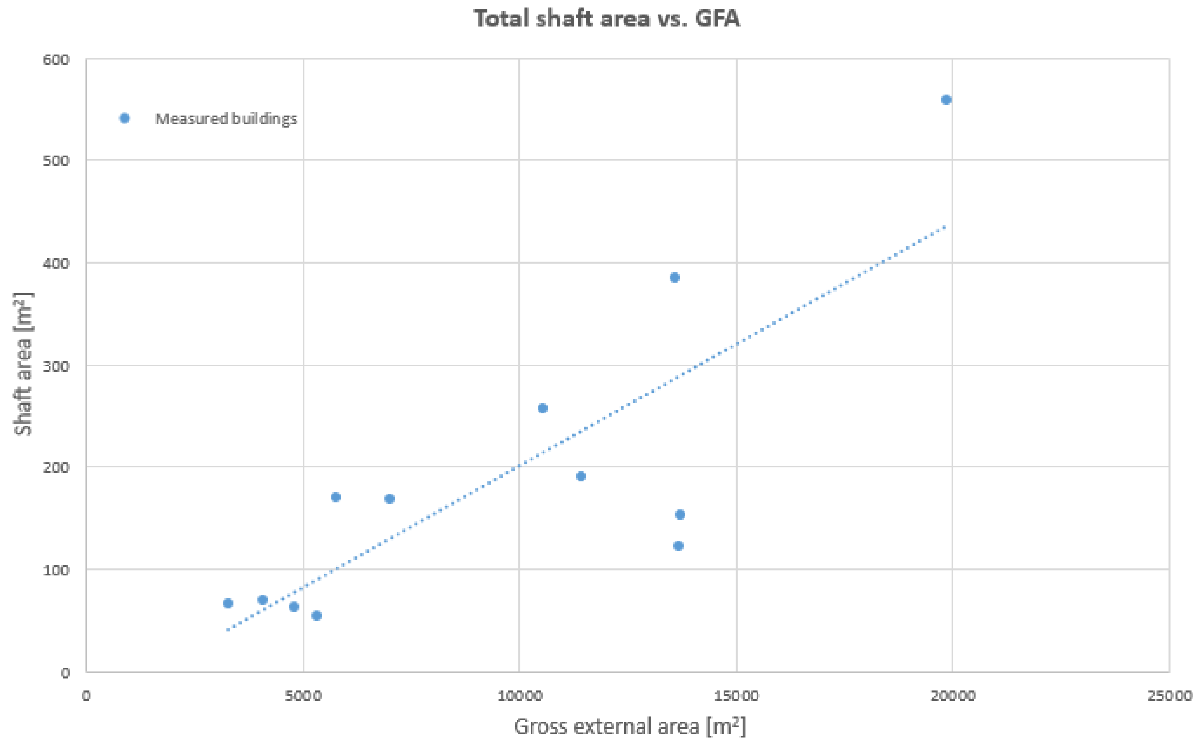


Figure 39. *Total shaft area measured in office buildings compared to measured gross external area.*

This measurement indicates that the office buildings considered in this thesis has a shaft area that is roughly 2.4 % of its GEA, with exceptions down to 1 %. The purpose of the graph is to enlighten the fact that there is area and thus money to be saved by making a good design.

5.3 VAV vs. Chilled beam scenario

This chapter presents the results on how the share of the air handling plant room area and the total shaft area varies with the gross external area of an office building. The theoretical office building is described in chapter 3, method. Based on measured buildings and the air handling plant model, two scenarios are developed. The first scenario is an office building with VAV system and the second scenario it has chilled beams instead.

With the share of AHU room area including shaft area on the y-axis and gross external area on the x-axis a relationship between the share of technical area and gross external area is established.

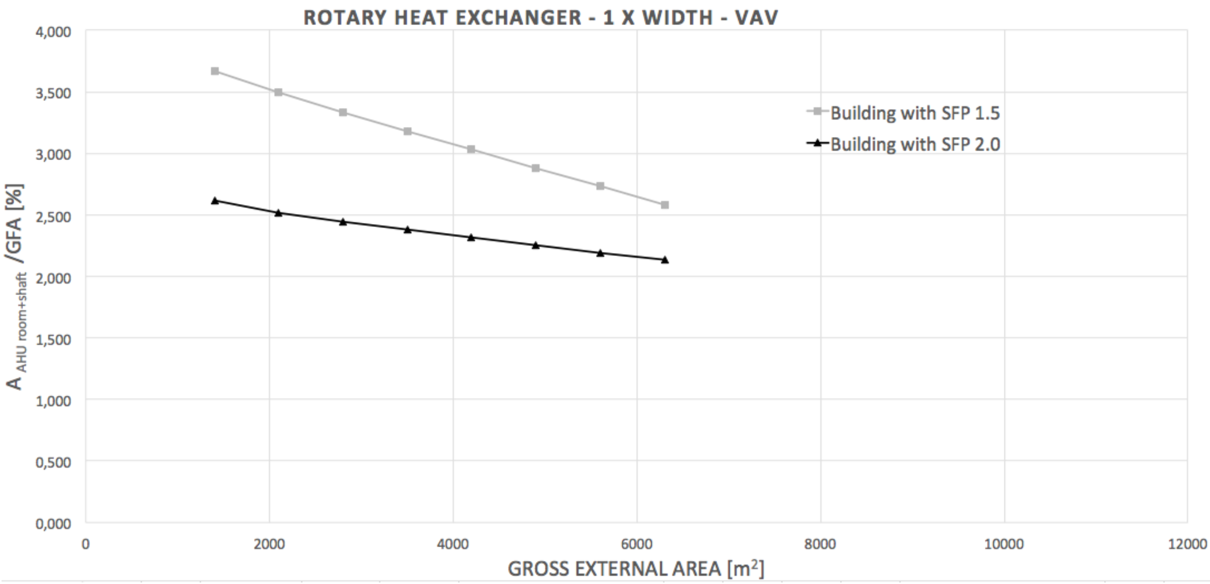


Figure 40. *Variable air volume scenario.*

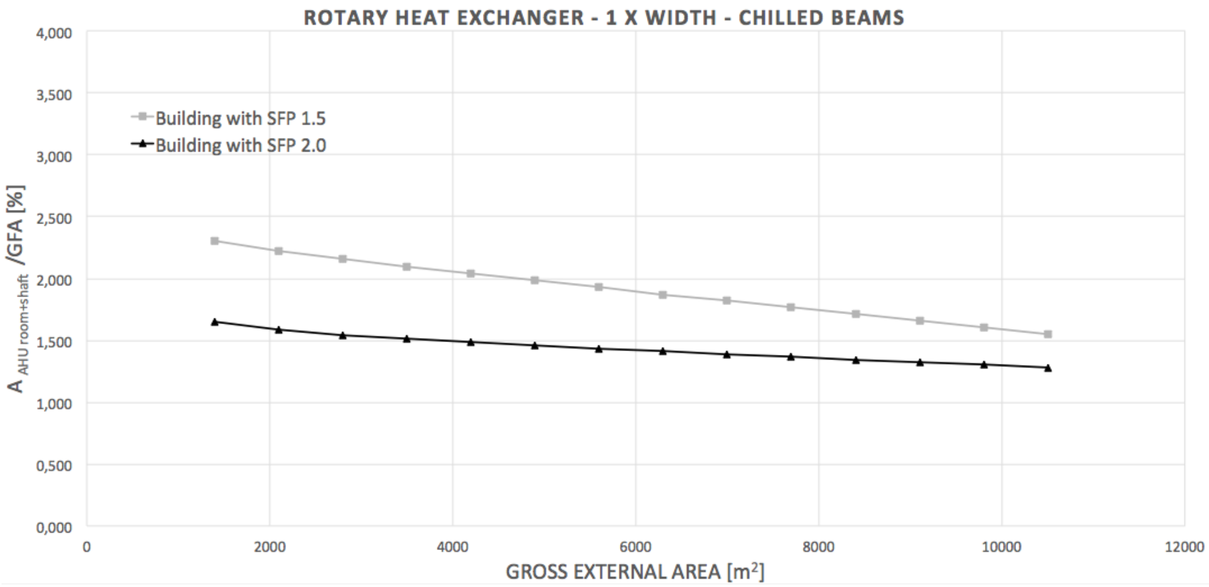


Figure 41. *Chilled beam scenario.*

A VAV system has a larger airflow than a chilled beam system, thus requires more space. These graphs show that a VAV system in an office building requires a larger share of technical space than a chilled beam system. The relation between the differences in the SFP 1.5 and 2.0 cases is proportional to each other. This is due to that the only difference is the airflow per floor area.

The graphs indicates that for a larger building the difference in space requirement for SFP 1.5 and 2.0 is smaller, thus not only a larger part of the gross external area can be occupied by tenants, it is more effective in terms of space, to have a lower SFP level of the air supply system.

6. Discussion & conclusion

This study examines how the air handling plant room geometry depends on SFP and airflow by using a theoretical model, how the total shaft area of an office building relate to the gross external area and ultimately examines the possibility to utilize the model together with the shaft area study to look at the economic impacts for various sizes of office buildings.

In the case study of shaft areas in existing office buildings shown in Figure 39 it is reasonable to believe that there is a relation between total shaft area and gross external area for a majority of the measured office buildings. But there is a wide variation depending on the design conditions that needs to be further categorized.

The graphs of the VAV and chilled beam systems are created with the air handling plant room model. This indicates that there is a possibility to use the model for other analyses but this requires a larger base. Thus economical evaluations are possible with further analysis.

The models results are illustrated in Figure 42, where the relation between optimal air handling plant room area and total airflow rate for a single air handling unit equipped with a rotary heat exchanger and varying SFP level is compared to Abels graph seen in Figure 1. Thus, there is a clear connection between total airflow rate and the air handling plant room area, and it does depend on the Specific Fan Power of the system.

The model is verified in chapter 5 where it is compared to measured office buildings; the conclusion is that the model seems to be consistent with reality. How is it related to the Abels work that is introduced in the beginning of this thesis?
The yellow trend line illustrates what is shown in Figure 1. What can be observed is that Abel's line follows the models SFP 1.5 line. How come, when the buildings Abels line is based on had an SFP around 2.5-3 kW/(m3/s)?
Some possible explanations could be:

- AHU with SFP 2.5 kW/(m3/s) is smaller today than when these measurements were conducted.
- Old ventilation systems were over dimensioned.

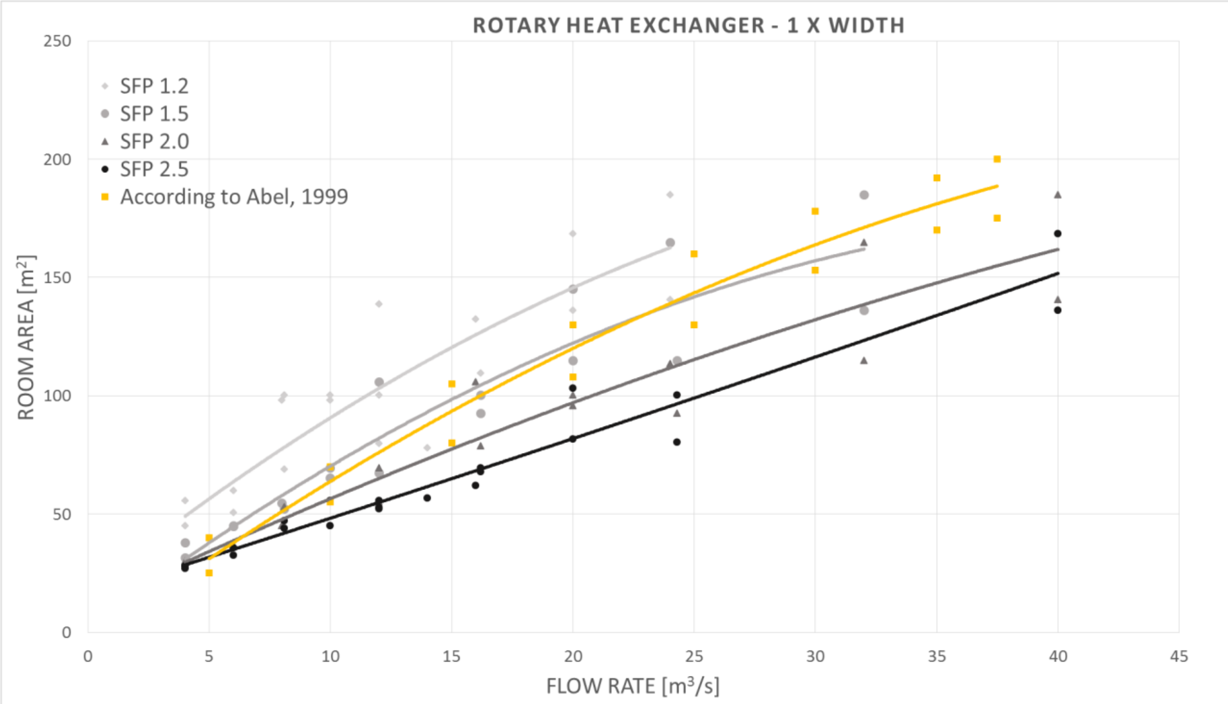


Figure 42. *The optimal air handling plant room area as a function of the total airflow rate for a single air handling unit equipped with a rotary heat exchanger compared to Abels graph in Figure 1. The service area is one width of the AHU, a.k.a. the small service area case. The trend lines in grayscale indicate the SFP levels.*

Since Abel's line follows the models SFP 1.5 line, the graph in Figure 1 is valid and usable for a modern design of an air handling plant room with SFP 1.5 kW/(m3/s). Or a reconstruction of an old building based on Abels graph will have enough available space for an air handling plant room with SFP 1.5 kW/(m3/s).

The models results for two air handling units are compared to Abels graph in Figure 43 below. The same observations are made here.

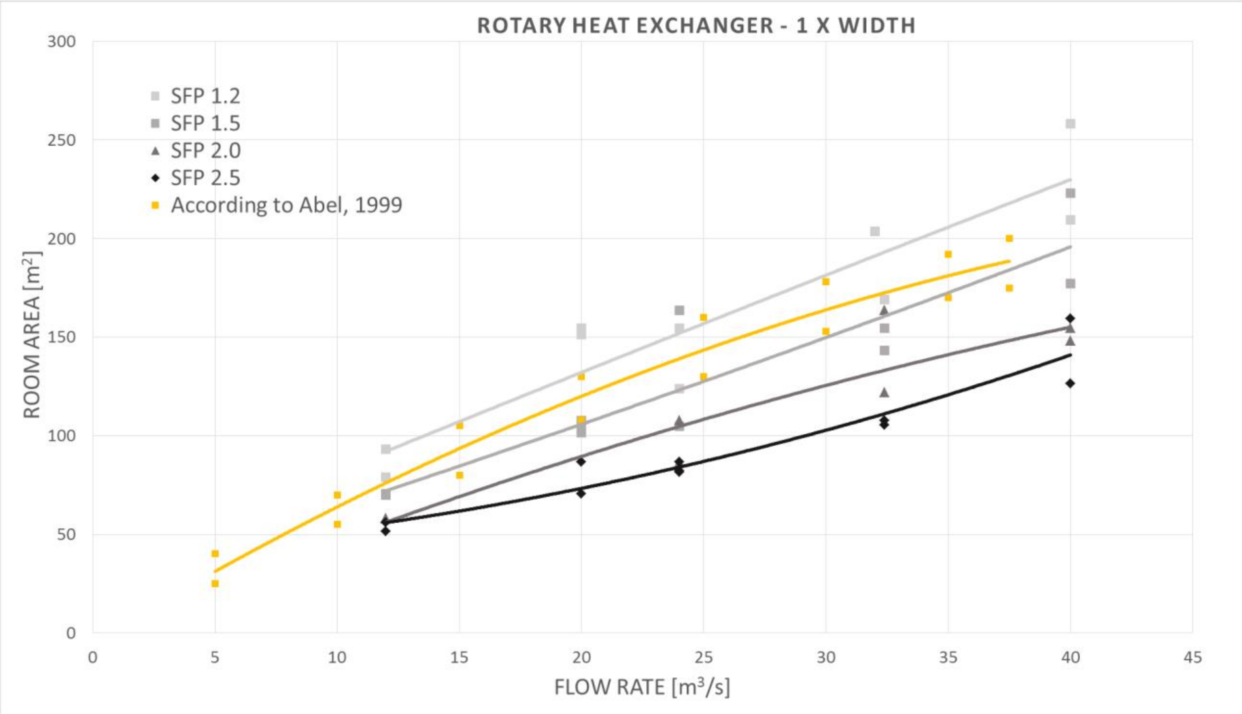


Figure 43. *The optimal air handling plant room area as a function of the total airflow rate for two air handling units equipped with a rotary heat exchanger compared to Abels graph in Figure 1. The service area is one width of the AHU. The trend lines in grayscale indicate the SFP levels.*

The models results are compared to Abels graph in Figure 44 below. The conclusion made from this comparison is that Abel's room height vs. flow rate is that the required ceiling height is insufficient to use as design basis. The reason for this is believed to be due to the change in geometry of the air handling units or that more units were used per airflow rate in the past than today.

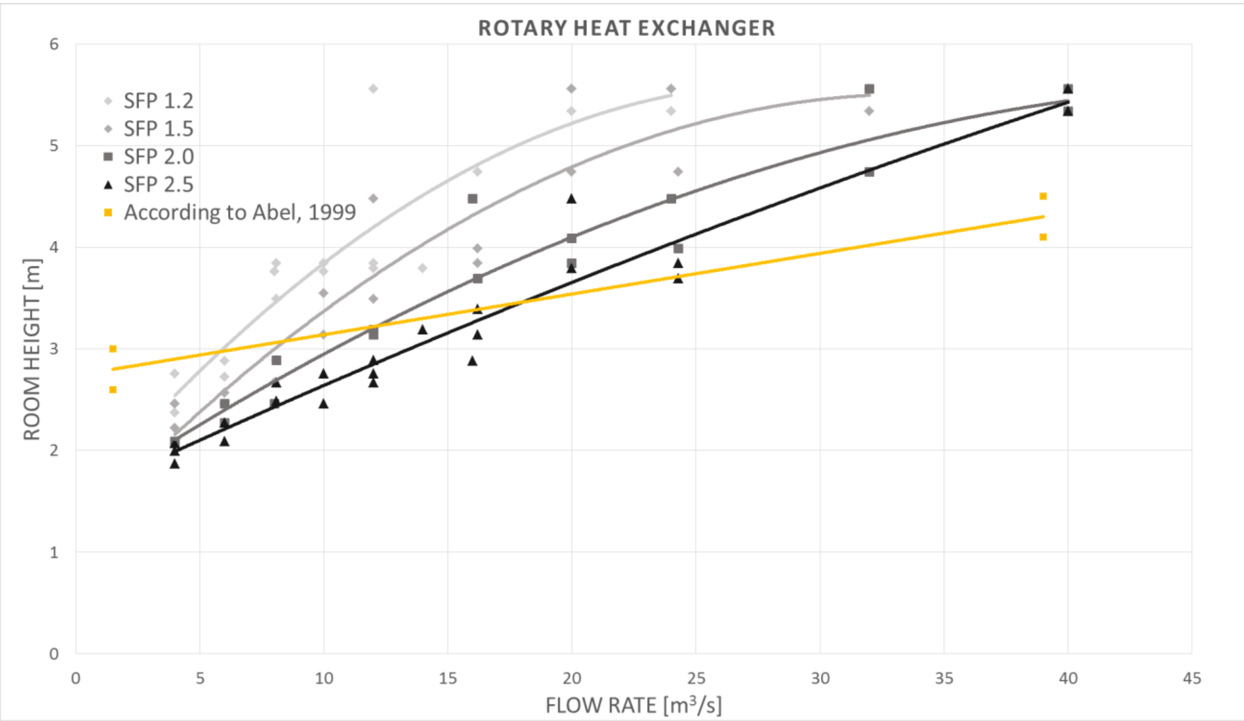


Figure 44. *Air handling plant room height as a function of the total airflow rate for units with rotary heat exchanger compared to Abels graph in Figure 2. The trend lines in grayscale indicate the SFP levels.*

Finally the results are illustrated in Figure 45 and 46, where the graph has been stripped down and extrapolated for illustration purpose.

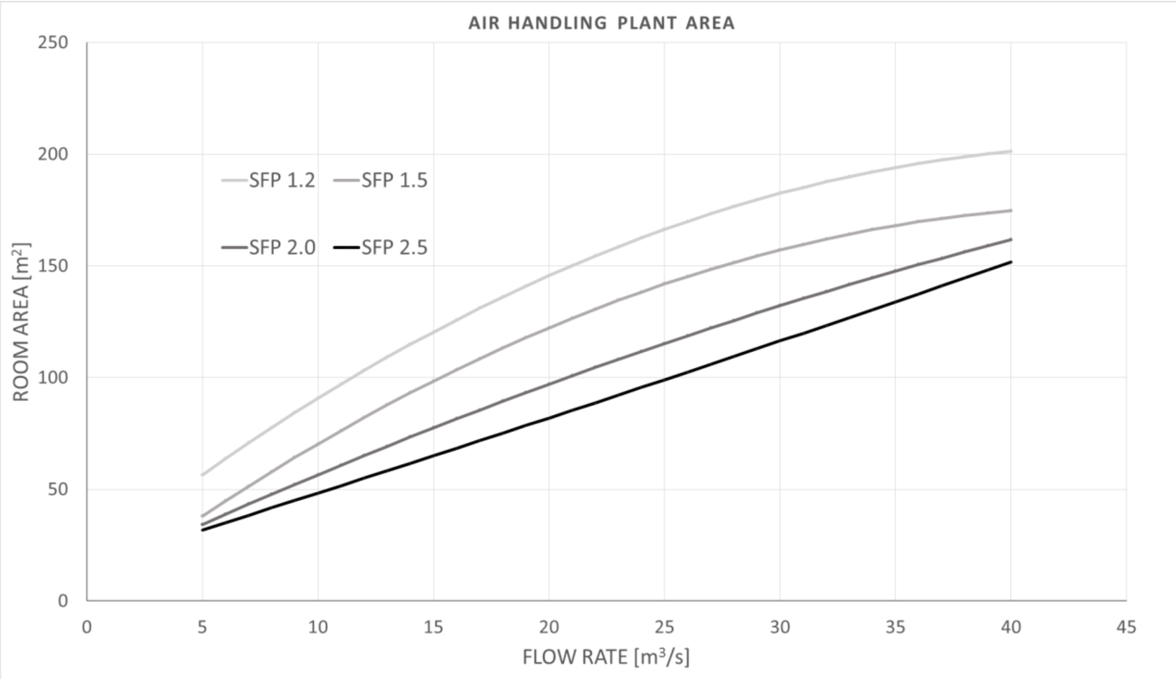


Figure 45. *The results from the air handling plant room model, where room area is a function of the total airflow rate. The trend lines in grayscale indicate the SFP levels.*

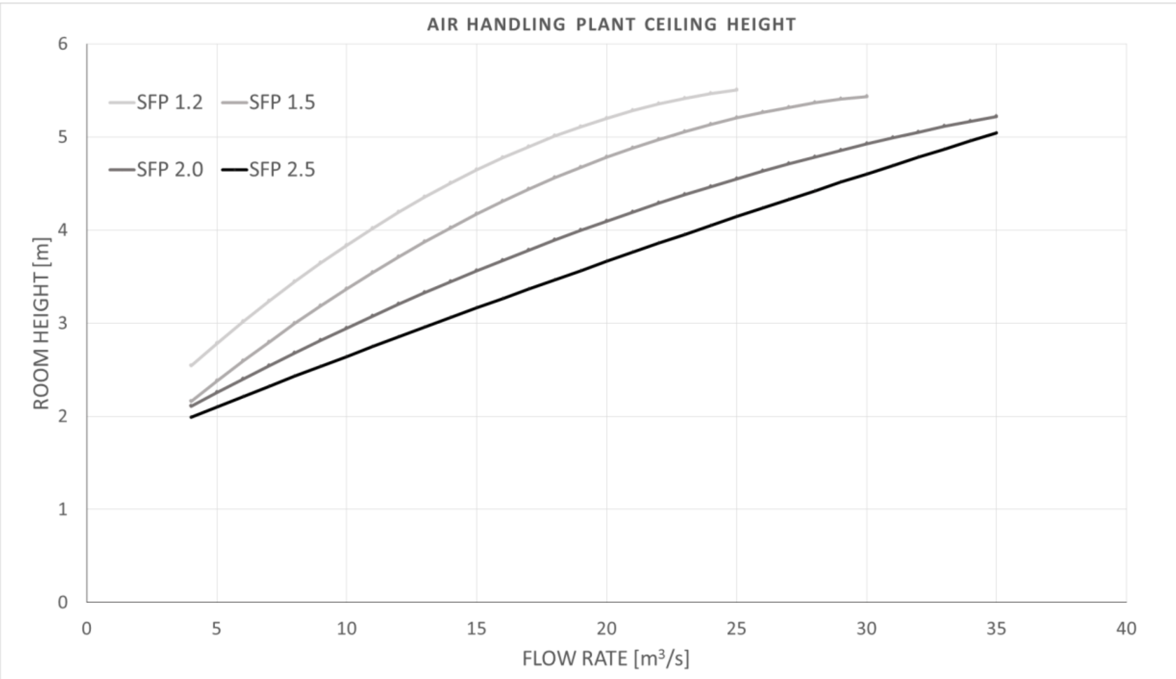


Figure 46. *The results from the air handling plant room model, where height is a function of the total airflow rate. The trend lines in grayscale indicate the SFP levels.*

Now that this thesis work is done several questions and uncertainties still remain, some final thoughts and ideas for future research:

- The assumptions made in the model, are they correct or what could have been changed?

- The study of space required for duct crossing requires more analysis to be a general valid assumption. For the building studied in this thesis it was good enough.
- It would be interesting to investigate more specific the difference between basement and top floor air handling plant room designs.
- The models results are compared to measured buildings and are in the same ballpark as the previous study made by Abel.

References

Software references

1. Swegon

2. Systemair

3. IV produkter

4. Welair

Litterature references

5. 2008 ASHRAE handbook: heating, ventilating, and air-conditioning systems and equipment.

6. Hur fungerar en shunt? Shuntab, 2003
http://www.shuntab.se/OvrigaDokument.asp then “Shuntutbildningar”

7. Teknisk handbook luftbehandlingsteknologi, Fläkt Woods

8. Projektering av VVS-installationer, Catarina Warfvinge & Mats Dahlblom, 2010.

9. Luftbehandlingsteknik, VVS 2000 TABELLER & DIAGRAM, Lennart Jagemar & Mattias Larsson, 2000.

10. Design of energy efficient buildings, Lennart Jagemar

11. International energy agency, Technical Note AIVC 65, Recommendations on Specific Fan Power and Fan System Efficiency.

12. Abel,E. 1999. Byggnaden som klimatsystem. CTH VIN085:1. Göteborg 1999.

13. Design of energy efficient buildings, Lennart Jagemar, 1996.

14. https://www.gov.uk/government/publications/measuring-practice-for-voa-property-valuations/code-of-measuring-practice-definitions-for-rating-purposes

15. http://www.energimyndigheten.se/sv/Hushall/Din-uppvarmning/Fjarrvarme/

16. Fjärrvärmecentralen utförande och installation, Svensk Fjärrvärme, 2014.

17. Tekniska bestämmelser för fjärrvärmecentralen, Göteborg Energi

18. HI-FOG http://www.marioff.com/fire-protection/hi-fogr-system-components/pump-units

19. Svensk standard SS 436 21 01, Electrical operating are for low-voltage switchgear and controlgear

Figure references

Figure 47. Plug fan without scroll housing.
https://www.dantherm.com/gb/ventilation/ventilation/danx-swimming-pool-air-management/

Figure 48. The different blade types for radial fans.
International energy agency, Technical Note AIVC 65, Recommendations on Specific Fan Power and Fan System Efficiency.

Figure 49. Plate heat exchanger and rotary heat exchanger.
http://www.engineeringtoolbox.com/heat-recovery-efficiency-d_201.html

Figure 50. Rotary heat exchanger.
http://www.rotorindustry.com/rotary_heat_exchanger.html

Figure 51. Lamina heat exchanger.
http://www.flaktwoods.se/0/0/2/4293030b-bd15-4dad-9904-d9a0217086fa page 107.

Figure 52. Distribution pattern plug fan.
Figure 53. Distribution pattern centrifugal fan.