Evaluation of ventilation for an office building

Situated in Gävle, Sweden.

Author: Erik Bergman

Year 2014
Abstract
Since the CO₂-emissions and electricity prices are ever increasing many companies have tried to reduce their energy consumption in order to reduce both CO₂-emissions and the cost of using energy. Therefore, in this article an office building situated in Sweden have been investigated with its current ventilation flow and what saving potentials can be made from heat recovery and a different ventilation flow in regards to health, energy and cost. Empirical data have been collected to be able to calculate energy savings made by heat recovery and new ventilation flow. A ventilation flow of 25 l/s per office were chosen and that the conference room should have at least 3 l/s per m² the dining room and locker was not investigated thoroughly and therefore a ventilation flow from the recommendations of Sweden was followed. The total flows became, 530 l/s respectively 630 l/s for the top and bottom floor. A rotating heat exchanger with an estimated efficiency of 80% was used for heat recovery and through the two methods combined an energy reduction up to 96,4 % for heating and 83,4 % from the electricity could be reduced.
Acknowledgements

My name is Erik Bergman and I am the author of this dissertation. I would like to thank all the people who have made this dissertation possible. A special thanks to my mentors at Stora Enso, Hannu Kiviharju, Madeleine Höglund, Mattias Brink and Ulf Larsson mentor at the university of the Gefle and Roland who gave assistance when Ulf was not available.
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1. Introduction

1.1 Background

In today’s society the necessity to establish energy efficient techniques have arisen over the last few years. Increment towards more energy efficient technology and renewable energy sources has increased due to the awareness and increase of both CO₂-emissions and the raising prices of oil and electricity.

In Sweden the increase of electricity prices nearly quadruple throughout year 2000-2010 as can be seen in Figure 1 where the electricity price rose from 125 to 550 sek/MWh. Therefore numerous companies in Sweden have tried to reduce their energy consumption. This is particularly important for companies with high energy consumption because they do not only contribute in a bigger scale but also have more earnings to make by lowering the energy use.

A major consumption of energy emanates from heating, ventilating and air conditioning (HVAC). As stated by (Vakiloroaya, Samali et al. 2014) indoor thermal comfort consumes about 50% of the total energy use for commercial buildings. Therefore, it would be highly profitable to reduce the energy consumed in the ventilating area, particularly since there are plenty of ways of dealing with the ventilation system and its consumption. This brings forth methods to avoid unnecessary costs. A well suited air flow and a good heat recovery system can reduce the energy consumed and thus, dealing with the issue of rising electricity prices and increment towards a more efficient society.

Therefore, various heat recovery systems and ventilation flows will be evaluated on an office building situated in Stora Enso, Sweden where the building has a HVAC system with no existing heat recovery. The ventilation flow needs to be sought out first since it directly affects the heat recovery.

![Figure 1: Visual display of electricity prices in Sweden from 2000-2010 acquired from nordpool (2014)](image-url)
1.2 Dimensioning of a Ventilation flow

A ventilation flow is dimensioned before the construction of the building. The air rate is dimensioned from standards that fit the location, amount of occupants and type of activity planned to be practiced. The standards are made from different companies and governments and are usually associated with a country. Hence, the standards vary depending on geographical locations but can also diverge by opinions on how much a structure should be ventilated and at what time the building were constructed.

The building examined has throughout the last 20 years gone through variations in amount of people, areas of each room and the ventilation rate for each area. Therefore, an uncertainty of how well the ventilation flow fits the current situation of the building needs to be investigated and if needed, changed to better fit the current situation of the building.

**Ventilation flow, work performance and profit**

For Nordic countries the air minimum exchange rate is 0.5 h\(^{-1}\) whereas for USA the exchange rate is 0.3 h\(^{-1}\) (Dimitroulopoulou 2012). This results in different opinions regarding a fitting regulation of air. For example the American standard, ASHRAE recommends a ventilation flow of 8,5 l/s for an office building with 20 m\(^2\) and one occupant (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Council 2010), meanwhile the Swedish standards (Svensson 2011, Middelman 2009) suggests having 14 l/s for the same area and occupants. A lower ventilation flow benefits the energy saving potential but might cause sickness and health related problems.

(Fisk, Black et al. 2012) states that the ventilation flow affect the performance of workers, energy use, sickness among staff and sick building syndrome. In Fisk’s article “Changing ventilation rates in U.S. offices: Implications for health, work performance, energy, and associated economics”

The Energy savings made by an increase of the ventilation flow was calculated for the whole world based on American offices, four quantities were projected:

- SBS symptom
- Work performance
- Short term absence
- The building’s energy use

By increasing the ventilation flow from 8 l/s to 10 l/s per person, (Fisk, Black et al. 2012) argues that it will give annual savings of 13 $ billion for the total office workers in the world of 41.3 million. It includes the cost of -0,05 $ billion by increasing the ventilation flow by 2 l/s per person which is a small investment compared to the earnings made. Furthermore, the increased work performance by the cumulating flow was estimated to 0,33 % per worker. Also, SBS symptoms were decreased by 5,2 % weekly which reduced short term absence by 9,4 million work days. When the ventilation flow was raised even further 8-15 l/s per person, annual savings enlarged to 37,5 $ billion.
It was argued by Säppänen, et al. (2006) that the performance of workers had a significant increase up to 15 l/s per person. A graph showing work performance increase in regards to ventilation flow was displayed, an increase of 2% was found within the interval 10-20 l/s per person. After that, the graph plunged and only had one percent increase from 20-45 l/s.

While the density of people is higher than 0,5 person/m² the likelihood of preserving a low contamination load and keep the productivity of workers low (under 6%) the airflow must be 3 l/s per m² or higher (Kosonen, Tan 2004). An acute focus is preferred during meetings to be able to comprehend and discuss critical matter. Hence, for the conference room a ventilation flow with a minimum of 3 l/s per m² ought to be achieved due to its high density.

By doubling the average ventilation rate to around 24 l/s per worker could reduce the sick leave absence in an office from 2 % to 1,5 %. Also it was described that the perceived air quality could affect the work performance of the staff where a higher dissatisfaction was developed when the apparent air quality was poorer. (Seppänen, Fisk 2006)

A high air flow can result in noises which can be regarded as uncomfortable for the residents. (Dahrlblom, Warfvinge 2010)

**Ventilation flow and CO₂-Concentrations**

The relation between the ventilation rate and the CO₂-concentration was displayed in a graph by (Milton, Glencross et al. 2000) where they had 2 buildings monitored on the CO₂ levels for 2 days straight. Building one had ventilation flows of about 11-13 l/s per person and building two had 23 l/s per person. Thus, building one yielded in a PPM of 800-900 and building two peaked about 600 PPM. A ventilation flow lower than 11 l/s per person may result in insufficient CO₂-concentrations (exceeds 1000 PPM). Therefore a minimum of at least 13 l/s per person is needed to assure that the PPM will not exceed 1000 PPM. The possibility of using a flow of 9 l/s is doable but can result in a PPM close to 1000.
1.3 Heat Recovery

In this section some of the most common types of heat exchangers will be discussed and weighed against each other to be able to make a decision of what type of recovery is most profitable in terms of energy savings.

Fixed Plate

In Figure 2 a visual picture of a plate heat exchanger can be perceived.

A plate heat exchanger’s efficiency is dependent on how the streams flow. If the stream is co-current the efficiency is generally lower than a counter-flow, although it depends acutely on how it is modelled but is generally higher conferring to (Yaici, Ghorab et al. 2013).

It was also contended by (Shurcliff 1988, Mardiana, Riffat 2013) that a counter flow yielded a higher efficiency than a co-current flow.

One type of plate heat exchanger is the enthalpy heat exchanger which was studied by (Nasif, AL-Waked et al. 2010). It was investigated with air to air as fluid under laboratory conditions. The enthalpy heat exchanger studied had a Z-configuration with a counter flow which supplied it with the possibility of recovering both latent and sensible heat.

It was found that the enthalpy heat exchanger provides efficiencies’ up to 75% respectively 60% for sensible and latent heating and a total efficiency of 70%. Although, the efficiency of the heat exchanger was decreased when the face velocity increased. The optimal velocity was found in the interval of 0,2-0,4 m/s. where measurements up to 3,0 m/s were evaluated. The enthalpy heat exchanger had a pressure drop reaching up to 400 Pa with variations of the flow from 0-2 m/s. The plummeting pressure results in the fan have to accommodate for the reduced air flow and hence, consume more energy.

As stated by (Abu-Khader 2012) a plate heat exchanger is “more commonly used in liquid-liquid heat transfer duties which require uniform and rapid heating or cooling.” Hence, it is not fitted for systems which utilize other media, as in this case, air to air transfer.
Rotary heat exchanger
Rotary heat exchanger is commonly applied for buildings due to their high efficiency. In Figure 3 a simple model showing a rotary heat exchanger with a counter-flow is shown. A rotary wheel can handle both latent and sensible heating simultaneously which increases the overall efficiency for the heat recovery.

According to (Nóbrega, Brum 2009) it is not unusual for a Rotary wheel to reach efficiency’s beyond 90%. However, in the article made by (Santos, Leal 2012) where a relation between energy use of buildings and ventilation rate was investigated, the theoretical efficiency used for the heat recovery was 80%. The disadvantage with a rotary wheel according to (Mardiana-Idayu, Riffat 2012) is the cross-contamination from the exhaust air to the incoming air. This is due to the rotating wheel which springs crossovers and leakage between the inlet and outlet air.

![Figure 3: Visual display of a Rotary heat exchanger](image)

Run-around
Run-around heat recovery can be applied when the supply pipe and exhaust pipe aren’t connected which is not possible for the other heat recovery types studied. This gives the Run-around heat recovery a big advantage of flexibility however, a disadvantage due to a lower efficiency (45-65%).

The run-around uses a fluid (usually water) as a carrier between the exhaust and incoming air. The fluid receives heat at the exhaust air and heats the supply air which can be seen in figure 4. Furthermore, a requirement for a run-around is the need of an extra pump which drives the fluid from the exhaust to the incoming air which consumes energy and extra installation costs. Also, an accumulator tank might be necessary to accommodate for the enlargement of the water when the temperature rises which increases the investment cost (Mardiana-Idayu, Riffat 2012)

![Figure 4: Visual display of a Run-around heat exchanger system](image)
1.4 Setup and limitations

To be able to investigate possibilities with the ventilation, critical information about the building has been obtained through visits, papers and by talking to people at the resident.

An office building with two floors will be investigated for this case study. The building was built in 1974 and has a surrounding workshop and faces another building at north which can be seen in figure 5. The area for the bottom and top floor is 287 m² respectively 318 m². One wall is faced towards the outdoor air and has four windows while the remaining walls are faced in the direction of the workshop.

The top and bottom floor have separate ventilation systems but works with the same principles.

The floors are ventilated with a mechanical ventilation system (no heat recovery) which heats incoming air with a heat coil. The indoor temperature is controlled by the exhaust air which is programmed to always be 22 °C for the top floor and 20°C for the bottom floor and the flow is constant.

The ventilation runs continuously throughout the year, this includes all holidays, weekends and nights. The ventilation systems also serve the surrounding workshop which has occupants around the clock. The ventilation goes to the surrounding workshop which works shifts and therefore cannot be turned off during nights and holidays.

The ventilation system will be rebuilt in the future which is why heat recovery and other air rates are a point of interest for the building.

People at the office work five days a week from 08:00-17:00. There are about 6 people actively stationed at the bottom floor and 10 people stationed at the top floor. There are plenty of people coming and going through the floors.

A Heating system is also used, where radiators carries hot water in order to heat all rooms. The floors have been investigated separately.

The office rooms will be top priority to establish an appropriate air flow since the building studied mainly consists of offices.
1.5 Aims of research
The aim of the dissertation is to evaluate the energy savings that can be made by heat recovery and a reduced ventilation flow and what annual profits can be made by these techniques. An aim of at least 70% of the energy used by ventilation should be reduced. Also, how can the work performance be improved?

1.6 Research question
• Dimension a new ventilation flow and select a heat exchanger for the case studied.
• Evaluate and Compare different energy efficient techniques for a ventilation system with regards to energy efficiency and annual savings by different techniques.

1.7 Criticism sources
The data gathered in the dissertation have been evaluated critically to maintain a high quality of sources accumulated. If a source has been cited in another article, the main source has been searched. If the main source could not be tracked to its origin, the journal was either treated with extra care by making sure the information collected could be found in more articles. Otherwise it was disregarded as a source of information due to lack of credibility.

Other sites that have been regarded as trustworthy are, governmental sites such as boverket.se, ashrae.org, av.se etc. These have been taken as reliable due to they represent standards for a country which uses credible sources and a lot of companies relies on the statements made by these standards. Course related literature for the energy section of HIG have been regarded as trustworthy, mainly because it has gone through some sort of investigation from HIG itself. Therefore, the data represented in course literature have been regarded as satisfactory.
2 Methodology

The methodology chapter will attempt to clarify the working process. Moreover, it will elucidate what methods have been chosen and why.

Both theoretical and empirical data have been gathered during this dissertation where most strategies and decisions originates from the information gathered which is then applied on the empirical data. Therefore, deductive reasoning has been applied for this dissertation.

To be able to dimension a new and evaluate the current ventilation flow and the potential of a heat exchanger, measurements must be made. Thus, quantitative data must be gathered and so, a quantitative method has been chosen. A quantitative method will give a fitting way of answering the research objective chosen.

2.1 Case study: Measurements

A case study has been selected to clarify the research question. A case study is a viable approach when facing an objective which demands deep knowledge of interior and exterior surroundings. This consumes a lot of time which means it is necessary to revolve around a single object, otherwise it becomes essential to have a greater interval of time to be able to do a firmly evaluation of the objectives chosen. Therefore in this article, where a deep knowledge of both the ventilation system and the building itself is desirable, a case study has been chosen.

To be able to dimension a new ventilation flow, the necessity to comprehend the size of the building, number of occupants and type of activity needs to be made clear. Through the case study empirical data have been gathered about the number of occupants and the type of activity in a particular zone which was gathered through visits to the building which can be seen in the appendix B, Table 7 and 10. A descriptive part about the building exists in 1.4 setup and limitations.

The amount of occupants for the conference room was set by counting the amount of chairs in the room; the same procedure was done at the dining room. Also, the area and volume was collected through drawings of the floors. A sketch of how the different floors looks can be seen in Appendix A, figure 8.
Internal Heat gain

The internal heat gain is the extra heat emitted from devices (including people) inside the building which will heat the incoming air by some percentage. Therefore, it plays an important factor on how much the heat recovery system can heat the incoming air.

The heat balance formula 2.1 describes the relation between heat gained and lost by a building. This is important since it will directly affect the ventilation system. In this dissertation the heat lost by transmission \( (P_t) \) has been neglected due to the building is surrounded by a workshop with similar temperature. Although, one wall is facing toward the outdoor air which will cause a loss through transmission. The internal gain would become greater if the transmission loss was taken into account but here it has not been done due to shortage of time. Furthermore, Air leakage \( (P_a) \) has not been included since it’s difficult to evaluate and gather any empirical data. Moreover, the workshop covers much of the outdoor space, which creates a minimal temperature difference. Hence, the air leakage will become trivial since the \( \Delta T \) between the workshop and the building studied is insignificant.

At the building studied 4 windows is facing outwards, the rest are faced into the mechanical station. The solar irradiation will give close to zero of extra heat since the wall is facing toward the north and have a building which blocks the solar irradiation which can be seen in figure 5, section 1.4. Therefore, \( P_s \) becomes 0.

The Heating system was assumed not to be active during measurements. A new formula to calculate \( P_i \) was achieved \( P_i = P_t \). Internal heat gain \( (P_i) \) could then be calculated by measuring the temperature for the in and out flow of the system. By subtracting the incoming air’s temperature from the exhaust flow’s temperature the difference becomes the \( \Delta T \) which gives internal effect by equation 2.1. Another way of estimating the internal heat can be done by appraising the total sum of equipment and occupants which emits heat. In this project both methods have been used but the method which measured the internal effect of equipment and occupants acted as a way of ensuring that the heat system was not active during measurements by checking that the internal effect given was not lower than the effect gotten from the \( \Delta T \) used in equation 2.1.

\[
P_t + P_v + P_l = P_w + P_s + P_i \tag{2.0}
\]

\( P_t \) = Heat lost by Transmission  
\( P_v \) = Heat lost by Ventilation  
\( P_l \) = Heat lost by Air leakage  
\( P_w \) = Heating system  
\( P_s \) = Solar irradiation  
\( P_i \) = Internal gains (computers, lamps, writer etc.)

Temperature measurement

Temperature measurements were carried out with resistance sensor. It measures the resistance which correlates with temperature and thus, gives the temperature. They were placed in the main ducts for the in and out flow for respective floors. The measurements were conducted from 04/04-14 to 04/15-14 which resulted in a period of 11 days which includes two weekends. The temperature during work days (08:00-17:00, no weekends) was used to calculate the temperature difference between the in and out flow of the system. Which is assumed to be the internal heat gain considering the heat system was presumed to not be active during measurements due to it could not be felt any heat coming
from the radiators during the placement of the resistance sensors. The temperature measurement over the measured period is displayed in figure 9.

Flow measurement
The ventilation flow has been measured empirically for two main channels, one which serves the upper floor and one for the bottom.

A flow meter measures the velocity through the relation between how much electricity is needed to keep the flow meter at the same temperature which gets heated or cooled when the stream passes by which makes it possible to measure the velocity in relation to the electricity use. The velocity was measured for a total of 9 measuring points which can be shown in figure 6. Where 6a displays the points measured through a crossectional view and 6b displays the measured points from above. Also, the ventilation flow has been measured in each room to be able to comprehend how the flow is distributed in each area which can be seen in Appendix A, figure 8.

Although, some outflows have not been possible to measure due to arduousness of height. The dining room located at the bottom floor was one of those measuring points and so the value was gotten by subtracting the total flow by the flow measured in each room. Therefore it is marked as a cross in figure 8 to display that there exist supply air but could not be measured. The total ventilation flow must be known in order to obtain the effect of heating the supply air.
2.2 Cost of ventilation

The ventilation consists of both electrical and heating consumption. The effect of heating the incoming air can be calculated by equation 2.1 where the effect demanded to heat to a certain degree is calculated.

\[ P = q \times \rho \times c_p \times \Delta T \]  
\[ (W) \quad (2.1) \]

- \( C_p \) = Heat capacity (kJ/kg\( \times \)k)
- \( q \) = Ventilation flow (m\(^3\)/s)
- \( \Delta T \) = The temperature difference between two fluids
- \( \rho \) = The density of the fluid (kg/m\(^3\))

In order to attain the annual savings and costs to heat the supply air, a duration chart is essential to acquire since it displays the temperature difference over a year which will affect how much the supply air needs to be heated in order to maintain a specific indoor temperature.

More often than not, the possibility of finding charts for different areas can be attained through different sites or books. For Gävle, no chart was found and hence, one was made by equation 2.2. (Hallén 1981) The formula utilizes the mean temperature over a year and the amount of hours that should be evaluated. By having access to a duration chart the possibility of calculating the heating cost for ventilation is possible. However, the ventilation also consumes electrical power when the fan runs. Therefore, it is needed to investigate the electrical consumption caused by the fan to evaluate the total consumption of the ventilation. A visual display of the duration chart can be seen in Appendix B, figure 13.

\[
T(h) = (h - 4380) \times (3.9 - 0.086 \times t_n) \times 0.001 + t_n + \left( h \times \frac{1 + \left( \frac{8 - t_n}{586} \right)}{8300} \right)^{3.8} - \left( \frac{1550}{(700 + h)} \right)^3 \\
+ 1.5 \times \left( \frac{t_n \times 1200}{8 \times (500 + h)} \right) \times \cos \left( \frac{900 - h}{585} \right) 
\]  
\[ ^\circ C \quad (2.2) \]

- \( h \) = Hours for a chosen period.
- \( t_n \) = Mean temperature for a year for a chosen area.

The affinity laws revolve around its parameter’s relationship between effect, revolutions per second, flow of air and the pressure drop of the fan. Through the relationship, calculation of the fan’s effect outtake during a specific flow can be predicted. Projection papers have been used in order to acquire the revolutions made by the fan and it’s effect, although the projection papers have not been possible to attach to this dissertation. Empirical data of the flow have been collected with a flow meter. The cost for electricity is taken from Stora Enso which can be seen in appendix B, Energy prices.

\[
\frac{q_1}{q_2} = \left( \frac{n_1}{n_2} \right)^1 
\]  
\[ (\mbox{-}) \quad (2.3) \]

\[
\frac{P_1}{P_2} = \left( \frac{n_1}{n_2} \right)^3 
\]  
\[ (\mbox{-}) \quad (2.4) \]

- \( q \) = Inlet and outlet flow. (m\(^3\)/s)
- \( n \) = Revolutions per second by fan. (rev/s)
- \( p \) = Effect of the fan (W)
2.3 Different ventilation standards

The presets to calculate the new flow can be made by data gathered in measurements but the question still stands on what flow is suitable. Therefore, 3 standards have been evaluated for the building to get a clearer view of what ventilation rate is profitable and if the flow lives up to the theoretical presumptions made in the introduction section.

**Swedish standard**

The Swedish standard is the lowest ventilation flow a building with occupants should have according to (Svensson 2011, Middelman 2009), where the amount of flow for a specific room is gotten from equation 2.5.

\[
q = 0.35 \times A + 7 \times P \quad \text{(l/s)} 
\]

\[A = \text{Area (m}^2\text{)}
\]

\[P = \text{Persons expected to occupy the room}
\]

\[q = \text{Air flow (l/s)}
\]

The 0.35 l/s per m² gives an air circulation about 0.5 h⁻¹ if the height of the room is 2.5 m. For areas where there are no people resident at all, an air flow of 0.10 l/s becomes the minimum requirement. The minimum requirement will be fulfilled through the air rate from the offices and corridors.

**Recommendations Sweden**

The recommendations of Sweden is supplying with guidelines for different types of areas. It springs information on how much ventilation flow is needed for a particular area with a specific type of operation. This is then calculated by equation 2.6 where the oms/h is given by (Enberg 2012) which assembles recommendations and restrictions given by Arbetsmiljöverket, Boverkets byggregler and Socialstyrelsens allmänna råd.

\[
q = n \times v 
\]

\[q = \text{Ventilation flow (m}^3/\text{h)}
\]

\[n = \text{How much the building should be ventilated per hour (h}^{-1}\text{)}
\]

\[v = \text{Volume of the room (m}^3\text{)}
\]

**ASHRAE standard**

The ASHRAE standard has been the choice for comparison between the Swedish standard and the recommendations of Sweden. The American standard treats the ventilation flow differently compared to Sweden with regards toward what airing rate a building should be ventilated with and hence an interesting comparison can be done. The American standard utilizes equation 2.7 where it resembles the Swedish standard but uses a slightly lower ventilation flow per m² and per person. (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Council 2010)

\[
V_{bz} = R_p \times P_z + R_a \times A_z \quad \text{(l/s)}
\]

\[V_{bz} = \text{Ventilation flow (l/s)}
\]

\[R_p = \text{People Outdoor Air rate (l/s)}
\]

\[P_z = \text{Persons expected to occupy the room}
\]

\[R_a = \text{Area Outdoor Air rate (l/s)}
\]

\[A_z = \text{Area (m}^2\text{)}
\]
**Flow by CO2 concentration**

From the article by (Milton, Glencross et al. 2000) it could be seen how the CO2 concentrations changes with the air flow. Although, to increase the confidence level of how it varieties, theoretical. PPM calculations have been made.

The CO2-concentration estimation is made to perceive the air quality in an area. Although, it should be noted by the reader that the big threat is not the CO2-concentration itself but rather is an estimation of how much the real pollutants have increased. CO2-concentrations are easier measured than most other pollutants and correlates with the pollutants in regards of growth. Therefore, the CO2-concentration is more commonly used as an indicator of air quality.

The PPM calculations made have only regarded the emission of CO2 caused by human breathing, and so it lacks the CO2 emissions caused by the surroundings, such as furniture. Therefore, the minimum ventilation flow displayed is when there is no furniture which emanates CO2 which in most cases are incorrect. Although, how the flow changes with the CO2-concentration still offer some guidance for a suited air flow.

The results are acquired from equation 2.8 where \( C_b \) have been assumed to 400 PPM which is the standard PPM for outdoor air. A visual display of how the flow differs with different CO2-concentrations can be seen in figure 10.

\[
q = C_b + \frac{P}{Q} \rightarrow q = \frac{P}{C-C_b} \quad \text{(m}^3/\text{s}) \tag{2.8}
\]

\( q = \) Ventilation flow achieved from a particular CO2-concentration. (m\(^3\)/s)

\( P = \) Generating CO2-pollutants from people. (mg/s)

\( C_b = \) CO2-concentration in incoming air (mg/m\(^3\))

\( C = \) CO2-concentration at equilibrium (mg/m\(^3\))
3 Results

This chapter will present results based on empirical data gathered from an office building located in Stora Enso, Sweden. A case study has been carried out to collect data for the ventilation flow and temperature. Data have been gathered to calculate the theoretical saving potential made by a heat exchanger and analyze the current and new ventilation flow. The heat exchanger savings will be calculated with the current flow and the one dimensioned in this dissertation. Also, what amount of energy can be saved by the two methods, separately and combined will be evaluated.

3.1 Selection of ventilation flow

The Swedish standard and the American standard has the lowest air rates which have made them not viable when dimensioning the flow since it is stated by (Fisk, Black et al. 2012) that the overall savings made by having a lower ventilation flow is negligible compared to the profits that can be made by actually increasing the flow.

Even though the flow was only increased by 2 l/s from 8-10 l/s the profit made was gigantic in comparison to the cost of increasing the air rate. Even if the numbers stated would contain major errors, the threshold between the statistics would be sufficient enough to not wager in favor of decreasing the air flow. Hence, having a flow around 15-30 l/s for each person could yield a suited environment with low risk of SBS and a highly regarded work performance.

A too high air flow will result in unnecessary expenses of the system which makes both the current ventilation flow and the recommendations of Sweden unfitting since it uses a flow over 40 l/s per office which can be seen in Appendix B, figure 12, which can also lead to draft and noises (Dahlblom, Warfvinge 2010). Therefore, the flow should revenue a pleasant air quality and a profitable increase on work performance but not be too immense.

A flow of 25 l/s per person is an appropriate flow for each office since it will also reduce the sick leave absence by 0,5% compared to the average ventilation rate of 12 l/s which will result in annual savings (Seppänen, Fisk 2006). For a conference room the minimum of 15 l/s per person should be sought since of the great density but should never go below 3 l/s per m². Since the conference room is 43 m² and has an estimated number of 20 occupants will give an air flow of 129 l/s. The dimensioned flow for the conference is 250 l/s which can be seen in Appendix B, figure 11a where the dimensioned flow is compared to the different standards and the measured flow.

The dining room and locker room for the bottom floor was not investigated thoroughly therefore the flow chosen follows the recommendations of Sweden because it has the highest flow which ensures a good air quality can be reached.
Figure 7 displays the total flow for each standard, the dimensioned flow and the reference flow. The total flow was acquired by adding each measurement for each point made which can be seen in Appendix A, figure 8.

The flow measured is higher than all standards investigated and also the one dimensioned. For the top floor the big difference were the corridor where the standards suggested a flow in the interval of 10-20 l/s and the flow measured was 608 l/s which can be seen in the Appendix B.
3.2 Selection of heat exchanger

In this project three different models of heat exchangers have been investigated, where the plated heat exchanger appears to have a lower overall efficiency than the rotary heat exchanger. The difference lingers around 20%. According to (Abu-Khader 2012) the plated heat exchanger is more commonly used for liquid to liquid which suggests using a rotary heat exchanger would be more suited since it both carries a higher efficiency and are well fitted for air to air as fluid even though it has the disadvantage of crossover and leakage.

The run-around exchanger is an excellent way of solving the problem when the pipes are not connected. This gives the run-around a huge flexibility in comparison to the other two exchangers. Although, in the case studied no postulation were that the pipes would not be connected and hence, the flexibility is not needed which suggests the usage of a rotary heat exchanger. Therefore, a rotating heat exchanger has been the choice for this project due to its high efficiency. The efficiency of the rotary heat exchanger has been chosen to 80% to ensure that the rotating heat exchanger not exceeds expectations of how much heat it can recover which is 10% poorer than what was stated by (Nóbrega, Brum 2009)
3.3 Internal gains

As can be perceived in table 1 the Internal heat gain is calculated by the amount of occupants, computers, copy writers and the area of light. The area of light for the ground floor have been changed to 170 m² (down from 318 m²), this is due to that many areas are not visited and so, the light is off most times during the day. Therefore only the areas where residents are situated will be regarded as a place where the light is on whereas internal gains are attained.

The internal gain acquired from empirical measurements (measuring of the in- and exhaust temperature) correlates well with the calculation of equipment as can be grasped in table 1. Since the effect of equipment and occupants are higher, the pre-estimation that the heat system was not on under measurements is therefore strengthened.

Table 2 displays the empirical temperature and flow gathered and the parameters needed to calculate the internal heat by equation 2.1.

The equipment and occupant calculation has been based on these presumptions about the effect of different objects.

A normal human emits 100 W, a computer 125 W, a write 400 W and light emits about 7,6 W/m² according to (Blomsterberg, Dalman et al. 2010)

<table>
<thead>
<tr>
<th>Flow (l/s)</th>
<th>Persons</th>
<th>Computers</th>
<th>Copy writers</th>
<th>Light (7,5w/m²)</th>
<th>Internal heat gain (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top floor</td>
<td>1085</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>287</td>
</tr>
<tr>
<td>Ground floor</td>
<td>951</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>170</td>
</tr>
</tbody>
</table>

Table 2: Estimation of the internal heat gained through equation 2.1, estimated by the temperature difference between the supply and exhaust air.
3.4 Effect reduction

In table 3 the annual energy use the fan can be seen. The Effect and revolutions per second have been taken from the projection papers. The energy used is based on the affinity laws to calculate the energy savings by lowering the air rate and hence, the effect of the fan.

Table 3: Displays the energy use of the fan for the reference system as well as the energy use by having a lower ventilation flow.

<table>
<thead>
<tr>
<th></th>
<th>Electricity use with current effect (MWh)</th>
<th>Electricity use with dimensioned flow (MWh)</th>
<th>Electricity reduced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top floor</td>
<td>26,1</td>
<td>2,6</td>
<td>89,9</td>
</tr>
<tr>
<td>Ground floor</td>
<td>13,1</td>
<td>3,9</td>
<td>70,2</td>
</tr>
<tr>
<td>Total</td>
<td>39,2</td>
<td>6,5</td>
<td>83,4</td>
</tr>
</tbody>
</table>

Compared to the reference, the electricity reduced by a lower flow is almost 90 % for the top floor respectively 70 % for the bottom floor and a total reduction of 83,4 % when combined.
3.5 Heat recovery and Ventilation flow reduction

In table 4 the total energy has been displayed for various methods. The values are calculated by equation 2.3 where the outdoor temperature is based off the duration chart found in the appendix, figure 13. The flow at the main ducts has been taken as the reference flow.

Table 4 only displays the energy used for a year with a specific method being applied, as reduced air flow or heat recovery. The dimensioned flow has been utilized for the reduced air flow. A rotating heat exchanger with an efficiency of 80 % has been the choice for heat recovery.

The heat recovery's great reduction derives from the internal energy which contributes in heating the supply air with another 50 MWh each year which makes it possible for the heat recovery to reduce the bought energy down to 18,9 MWh. Meaning the heat recovery really utilizes 80% (the efficiency) of 350 MWh to heat the supply air.

Table 4: Shows the potential energy savings made by heat recovery, reduced air flow and both methods at once. Total energy used has been regarded as the reference point which is the current situation for the building

<table>
<thead>
<tr>
<th></th>
<th>Bought energy (MWh)</th>
<th>Internal energy (MWh)</th>
<th>Reduced air flow (MWh)</th>
<th>Heat recovery (MWh)</th>
<th>Both (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top floor</td>
<td>158,5</td>
<td>35</td>
<td>73,8</td>
<td>9,6</td>
<td>4,5</td>
</tr>
<tr>
<td>Bottom floor</td>
<td>141,7</td>
<td>17,5</td>
<td>94,6</td>
<td>9,4</td>
<td>6,3</td>
</tr>
<tr>
<td>Total</td>
<td>300,2</td>
<td>52,5</td>
<td>168,4</td>
<td>18,9</td>
<td>10,7</td>
</tr>
</tbody>
</table>

For table 5 no investment cost or reparation expenses have been regarded only the cost for having the system running.

Table 5: The annual cost of different methods applied to the reference (current situation) of the system

<table>
<thead>
<tr>
<th></th>
<th>Reference cost (kr)</th>
<th>Reduced air flow (kr)</th>
<th>Heating cost with heat recovery + reduced air flow (kr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating</td>
<td>Electrical</td>
<td>Heating</td>
</tr>
<tr>
<td>Top floor</td>
<td>31705</td>
<td>9198</td>
<td>14757</td>
</tr>
<tr>
<td>Bottom floor</td>
<td>28331</td>
<td>4599</td>
<td>18917</td>
</tr>
<tr>
<td>Total</td>
<td>60036</td>
<td>13797</td>
<td>33674</td>
</tr>
</tbody>
</table>
**Cost of buying heat and electricity**

For the case studied, heating costs 20 öre/kWh and for the electrical consumption a price of 35 öre/kWh which can be seen in appendix B, energy prices.

A lower flow reduces the total energy for the electrical part by 83,4 % (11500 kr) and the heating by 56% (26362 kr). This gives annual savings of 37862 kr.

The heat recovery reduces the electrical part by 0% and the heating by 93,6 %. This gives annual savings of 56246 kr.

When combined a saving potential of 83,4% (11500 kr) by electricity reduction and another 96,4% (57891 kr) by heating can be saved, resulting in total annual savings of 93,9% (69391 kr of 73833 kr).
4 Discussion

4.1 Dimensioned flow

The measurements have been collected momentarily for the ventilation flow which gives uncertainties on how well the measured flow correlates with the flow for a year. The uncertainties are strengthened when the combined measured points for the top floor are compared to the one measured at the main duct. Shockingly enough, the measurements made at the top floor are greater than the flow in the main duct, which should not be possible. Therefore, the flows measured are inexact and so the calculations of energy and cost of the reference flow contains errors. Knowing the interval of the error would be a great profit for the project but have not been possible to evaluate. The reason why the main duct’s ventilation flow was chosen as the reference and not the measured point’s combined flow was because they used more measurements since it was more ducts to measure and so it was held that the error would become greater with the more measurements made.

The dimensioned flow was higher than most standards chosen due to its relation to increase the work performance and achieve a better suited environment. Although, the results on how much increase in work performance it would yield with a stronger flow is highly uncertain. This is due to the reason that the data collected is heavily affected by numerous variables. Thus, it may not be that accurate but it is still believed by the author of the dissertation that it will give a positive effect of the work performance and hence it becomes worth increasing the flow.

When the ventilation flow decreases some parameters will inevitably change. The temperature can greatly be affected by halving the ventilation flow since a reduced air rate gives internal effects more time to heat up the air and so a greater internal effect can be achieved. Although, as stated earlier lower ventilation flow yields a higher temperature which makes it harder to cool the building down during summers. Since the cooled air will be traveling slower and the internal heat will be greater it can result in the need of greater cooling of the supply air alternatively increase the air flow during summer.

A lower ventilation flow also contributes to a lower sound caused by ventilation which can increase the workers comfort which has not been evaluated firmly but at least has been acknowledged.

The air rate for office was dimensioned to 25 l/s which did not really take into account the volume and area of the room. In Appendix B, table 8 and 9 it is displayed that most of the offices had an area about 20 m². There are some of the offices which only have 11 m² which gives a possibility that the ventilation flow for the smaller offices might be to great and can spring drafts.

At the start of the project I got to know that turning of the ventilation flow was not possible due of having occupants working at the surrounding workshop. Therefore, no thought was taking into turning off the ventilation system. Although I did not consider the possibility of lowering the ventilation flow during nights and weekends so it would give a fitting flow to the workshop, which is a great method of increasing the energy saved.
The flow of 25 l/s was chosen to increase the work performance which was based off a scientific article which was a bit uncertain, therefore the flow selected might be considered a pretty immense flow since only one person and one computer occupies the room. Therefore, an even lower flow could have been preferred to further reduce the ventilation flow and thus receiving a decrease in the heating and electrical consumption. Furthermore, even if the flow would be reduced, the air quality with 25 l/s is much higher than it actually needs to be and hence, even if the flow would be lowered the air quality would still be suited as long as the flow does not go below 9 l/s since that might cause the risk of getting a PPM over 1000 and so, the risk of a bad air quality.

4.2 Heat exchanger

The heat exchanger’s efficiency has been chosen to 80%. This is below the efficiency which was stated by (Nóbrega, Brum 2009). Therefore, the efficiency might become even higher and thus, the annual energy savings too. Although, to make sure the energy saving potential is not actually lower than what is given by this dissertation a lower efficiency was picked. Even though it was argued by (Nóbrega, Brum 2009) that the efficiency was commonly 90% is somewhat hard to believe. This is due to the fact that it will be leakage and cross-contamination through the exchanger which was argued by (Mardiana-Idayu, Riffat 2012). Therefore it is safer to assume that the efficiency of the heat exchanger is a little lower than 90% therefore an efficiency of 80% was chosen. The efficiency selected was strengthened due to (Santos, Leal 2012) who also used 80% efficiency for his experiment.

4.3 Fan Effect

The reduced effect for the fan is calculated by the fan’s parameters which were taken from a projection paper. Since the building was constructed at 1974 the fan was assumedly installed close thereafter. Therefore, the projected speeds and effect consumption of the fan can contain errors on both the projected estimations of the fan’s parameters but also not correlate with the current (measured) air flow. This gives a possibility that the reduced electricity cost which was calculated by the affinity laws may contain errors since the flow might not correlate with the parameters given by the projection papers.

4.4 Internal gains

Internal gains were given by the \( \Delta T \) used in equation 2.1 which was measured over 7 work days in April. The internal effect may vary over a year due to changes made of working force and equipment. Therefore, the energy cost for the heat exchanger may fluctuate during different seasons which has not been taken into account.

By neglecting the transmission from the north side of the building and the windows, might interfere with how much the internal effect becomes. However, it should be noted that both these neglects would contribute to a greater internal effect. Therefore, it would only contribute to greater savings. This is because the internal heat can be seen as free energy and hence, the free energy can be used to heat the supply air which leads to reduced costs and energy consumption.

4.5 Heat recovery with Ventilation flow reduction

The combination of the two methods has thorns due to that the heat recovery recovers an immense part of the total heating which results in that the reduced ventilation flow will not recover much heat in combination with heat recovery. Although the good part is that the flow reduction also lowers the electricity usage of the fan which the heat recov-
ery cannot. Both methods are great ways of reducing the energy use and cost for the ventilation system.

The cost of installation and maintenance of the equipment have not been regarded which makes it hard to really compare the methods in cost reduction since that is highly dependent on how much you need to invest on the different methods. This has not been regarded since the reconstruction of the ducts will be done in a near future and it’s hard to say how it will be projected and what dimensions the new ducts will have which makes it both hard to estimate if it is even needed to have a regulator of the flow and how large the heat recovery would need to be which takes a great amount of time.

Although, I believe that it would still be of great value to know what the investment costs are since it helps in the comparison of the two methods and gives a way of seeing what payoff-time the different methods would have separately but also in combination.

I would not be in the opinion that one of the methods is superior to the other. I believe both methods are excessive depending on what you are interested in reducing, if it’s the electrical or the heating (or both) determines the method a building should use. Although, an investment cost of the different methods needs to be collected in order to make a fair assessment. Including size of pipes, and how the ducts should be rebuilt.

Since the electricity price has been increasing substantially the last years, increases the value of lowering electricity use of the ventilation. Hence, over a long time scale the reduced air flow might be superior but of course depends on the situation of the building.
5 Conclusion

A ventilation flow of 630 l/s was chosen for the bottom floor and a ventilation rate of 530 l/s for the top floor to fulfill a flow suited. A rotating heat exchanger has been the choice of heat exchanger for the case studied since it bears the highest theoretical efficiency.

The heat recovery is best in regards to decreasing the annual cost of heating where it reduced the energy from 300 MWh (60 000 kr) for the case studied down to a measly 18,9 MWh (4000 kr).

The lower ventilation flow reduces the heat cost yearly and could decrease the reference cost from 60 000 kr down to 33 000 kr with no heat recovery. However, the reduced ventilation has also great earnings to make through the fans electrical consumption where the reference flow resulted in an energy use of 39,2 MWh (13797 kr) could be reduced to 6,5 (2297 kr) each year. If combined the total cost of the heating section would become 2000 kr and a cost of 2297 kr for the electrical part compared to the reference where the cost of heating is 60 000 kr and 13797 kr for the electric consumption.

A total energy reduction of 94 % (69300 kr) can be achieved when both methods are applied. A lower flow reduces the total energy for the electrical part by 83,4 % and the heating by 56%. The heat recovery reduces the electrical part by 0% and the heating by 93,6 %.
Reference list


Appendix A: Sketches

Sketches

Figure 8 shows the drawings of the floor plans. The scale is not accurate but functions as a visual indicator of how the building is formed and what type of areas there are. Furthermore, the “x” Symbol explains where measurements have been taken for specific areas. The vertical cross describes areas where supply air exists but could not be measured. Hence, the dining room and archives since ducts were located at the ceiling and could not be reached.

![Figure 8a: Visual display of the top floor](image)

![Figure 8b: Visual display of the bottom floor](image)
Appendix: B Empirical data

Empirical data
Variations of temperature were taken from empirical measurements of the ventilation flow for the main ducts of the in- and out air rate.
As can be seen in figure 9 the exhaust air did not alter as much as the supply air. However, due to the ventilation system is programmed to maintain a constant flow and a constant temperature for the exhaust air, supply air must vary in order to compensate for the variations of the outdoor temperature and other shifting variables such as internal heat.

The plummeting parts of the graphs originate from an increase in either internal heat or a heat system is turned which gives extra heat. Therefore, the temperature for the incoming air needs to decrease in order to keep the exhaust air at 22 respectively 20 degrees for the top and bottom floor. Since the alteration is ranging from 2-4 degrees and at a closer look can be seen to occur at 08:00 it is safe to assume that it is due to employees have arrived in the building and electrical components such as computers and lamps have been turned on which increases the internal effect.

![Figure 9: Displays the temperature variations for the top and bottom floor. Incoming air are marked with blue and red is the exhaust air.](image)
Reference Ventilation flow

The branches are ducts which exists from the main duct and goes into the workshop, therefore they have been subtracted from the total flow to be able to just take the flow which goes into the office building.

Table 6: Displays the reference flow for the top and bottom floor

<table>
<thead>
<tr>
<th></th>
<th>Total flow (m³/h)</th>
<th>Branches (m³/h)</th>
<th>Flow without branches (reference flow) (m³/h)</th>
<th>(l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow top floor</td>
<td>3960</td>
<td>54</td>
<td>3906</td>
<td>1085</td>
</tr>
<tr>
<td>Flow bottom floor</td>
<td>3823</td>
<td>399</td>
<td>3424</td>
<td>951</td>
</tr>
</tbody>
</table>

Areas and dimensioned flows

In table 7 and 10 the quantities of area and volume have been taken from drawings for the floors. Number of persons in each area has been acquired by talking to people and by visits to the building.

Some of the rooms have not been displayed since they only ought to be supplied with exhaust air which is not evaluated for this project.

Different flows have been presented in Table 8 and 9 from various ventilation standards. Also the measured air rate is shown and the one dimensioned. There was no flow at the bottom floor at the corridors which is why the flow becomes zero. Where a (-) symbol is shown, a flow could not be obtained. For example there were no guide lines from the recommendations of Sweden on what a suited flow for a corridor were to be and so it has not been regarded in the matter, hence the (-) symbol.
### Table 7: Display of different quantities for the bottom floor

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
<th>Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office 1</td>
<td>16</td>
<td>61</td>
<td>1</td>
</tr>
<tr>
<td>Office 2</td>
<td>28</td>
<td>106</td>
<td>1</td>
</tr>
<tr>
<td>Office 3</td>
<td>11</td>
<td>41</td>
<td>1</td>
</tr>
<tr>
<td>Office 4</td>
<td>11</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Office 5</td>
<td>11</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Office 6</td>
<td>11</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Common room</td>
<td>20</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td>Corridor 1</td>
<td>25</td>
<td>94</td>
<td>0</td>
</tr>
<tr>
<td>Corridor 2</td>
<td>22</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>Dining room</td>
<td>51</td>
<td>191</td>
<td>20</td>
</tr>
<tr>
<td>Locker room</td>
<td>32</td>
<td>118</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 8: Different flows calculated from the three ventilation standards (bottom floor)

<table>
<thead>
<tr>
<th>Type</th>
<th>Recommendations Sweden (l/s)</th>
<th>American Standard (l/s)</th>
<th>Swedish standard (l/s)</th>
<th>Flow measured (l/s)</th>
<th>Flow dimensioned (l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office 1</td>
<td>51</td>
<td>7</td>
<td>13</td>
<td>43</td>
<td>25</td>
</tr>
<tr>
<td>Office 2</td>
<td>88</td>
<td>11</td>
<td>17</td>
<td>93</td>
<td>25</td>
</tr>
<tr>
<td>Office 3</td>
<td>34</td>
<td>6</td>
<td>11</td>
<td>47</td>
<td>25</td>
</tr>
<tr>
<td>Office 4</td>
<td>36</td>
<td>6</td>
<td>11</td>
<td>51</td>
<td>25</td>
</tr>
<tr>
<td>Office 5</td>
<td>36</td>
<td>6</td>
<td>11</td>
<td>56</td>
<td>25</td>
</tr>
<tr>
<td>Office 6</td>
<td>36</td>
<td>6</td>
<td>11</td>
<td>55</td>
<td>25</td>
</tr>
<tr>
<td>Corridor 1</td>
<td>-</td>
<td>8</td>
<td>9</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Corridor 2</td>
<td>-</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Common room</td>
<td>63</td>
<td>25</td>
<td>42</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>Dining room</td>
<td>255</td>
<td>148</td>
<td>158</td>
<td>255</td>
<td>250</td>
</tr>
<tr>
<td>Locker room</td>
<td>158</td>
<td>-</td>
<td>81</td>
<td>64</td>
<td>150</td>
</tr>
<tr>
<td><strong>Total flow</strong></td>
<td><strong>756</strong></td>
<td><strong>228</strong></td>
<td><strong>370</strong></td>
<td><strong>705</strong></td>
<td><strong>630</strong></td>
</tr>
</tbody>
</table>
### Table 9: Display of different quantities for the top floor

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
<th>Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor</td>
<td>56</td>
<td>210</td>
<td>0</td>
</tr>
<tr>
<td>Office 1</td>
<td>16</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Office 2</td>
<td>18</td>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>Office 3</td>
<td>23</td>
<td>68</td>
<td>1</td>
</tr>
<tr>
<td>Office 4</td>
<td>24</td>
<td>98</td>
<td>1</td>
</tr>
<tr>
<td>Office 5</td>
<td>21</td>
<td>55</td>
<td>1</td>
</tr>
<tr>
<td>Office 6</td>
<td>14</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>Office 7</td>
<td>15</td>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td>Conference room</td>
<td>43</td>
<td>112</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
<th>Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor</td>
<td>56</td>
<td>210</td>
<td>0</td>
</tr>
<tr>
<td>Office 1</td>
<td>16</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Office 2</td>
<td>18</td>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>Office 3</td>
<td>23</td>
<td>68</td>
<td>1</td>
</tr>
<tr>
<td>Office 4</td>
<td>24</td>
<td>98</td>
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</tr>
<tr>
<td>Office 5</td>
<td>21</td>
<td>55</td>
<td>1</td>
</tr>
<tr>
<td>Office 6</td>
<td>14</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>Office 7</td>
<td>15</td>
<td>53</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 10: Different flows calculated from the three ventilation standards (top floor)

<table>
<thead>
<tr>
<th>Type</th>
<th>Recommended (l/s)</th>
<th>American Standard (l/s)</th>
<th>Flowmeasured (l/s)</th>
<th>Flow dimensioned (l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor</td>
<td>20</td>
<td>17</td>
<td>608</td>
<td>30</td>
</tr>
<tr>
<td>Office 1</td>
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<td>35</td>
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</tr>
<tr>
<td>Office 2</td>
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<td>Office 3</td>
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<tr>
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<td>8</td>
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<tr>
<td>Office 6</td>
<td>15</td>
<td>10</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Office 7</td>
<td>16</td>
<td>10</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Conference room</td>
<td>50</td>
<td>6</td>
<td>222</td>
<td>250</td>
</tr>
<tr>
<td>Office 8</td>
<td>14</td>
<td>9</td>
<td>69</td>
<td>25</td>
</tr>
<tr>
<td>Office 9</td>
<td>12</td>
<td>7</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Office 10</td>
<td>12</td>
<td>7</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Total flow</td>
<td>204</td>
<td>667</td>
<td>103</td>
<td>1176</td>
</tr>
</tbody>
</table>
**PPM-calculations**

Figure 10 represents different flows to maintain a specific CO₂-concentration. The graph was made by theoretical calculations that only regarded the CO₂-concentration that was released from one person of an average weight of 75 kg. The graph ranges from 600-1000 PPM. It can be seen that the graph is not linear and hence the CO₂-concentration demands higher and higher flows for a steady decrease in CO₂. This also implies a greater cost to reduce the CO₂ by one step.

![Figure 10: Shows how the ventilation is related with the Co2 Concentration](image_url)
The conference and corridor are located at the top floor. For a further display of how the floors are composed and measuring points see Appendix A, figure 8. The biggest difference was the corridor at the top floor which can be seen in figure 11a. Where most standards suggests having a pretty low flow since it is not regarded as an area which people will be staying at and therefore a very low flow is suggested. The measured flow is much greater than what criterions advocates. This could perhaps be explained by reconstructions of the areas. The flow dimensioned for the conference room is the most immense flow.

Figure 11b shows the supply air for the bottom floor where a dimensioned flow has been created. The recommendations of Sweden suggest no ventilation flow onto the corridors which also was the measured case since there was no supply air for the corridor.

![Conference room and Corridor top floor](image)

**Figure 11a: Shows the Conference room and corridor located at the top floor**

![Conference room, common room and corridors bottom floor](image)

**Figure 11b: Shows the Conference room, dining room, locker room and corridor located at the bottom floor**
Figure 12 shows the different air rates for the offices, it can be perceived that the recommendations Sweden have the most immense flow for the top level due to that the volume of the offices are large, which is caused by the height. At the bottom level the height is not that big which results that the flow measured have the highest air rate.
In figure 13 it can be seen how much energy (area between two lines) is needed to heat to a certain point. The area below the blue line and above the purple shows the energy needed to heat by other means than heat recovery since it will not be able to rise the temperature high enough. The duration chart have been made in order to calculate the energy saving potential of heat exchanging, which has been done for the reference flow and the one dimensioned.

**Figure 13: Duration Chart of Gävle, Sweden. Shows the temperature variation over a year.**

**Energy prices**

"När du räknar på en kostnadsbesparing pga att du energieffektiviserar ventilationen så kan du räkna på att den el vi sparar kostar 300kr/MWh (beräknat medelspotpris för 2014) + elskatten som är 5kr/MWh. Det totala elpriset är högre pga nätkostnaden och annat men det påverkas inte om vi minskar förbrukningen något." (Madeleine Höglund Energy manager of Stora Enso)