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MASTER'S THESIS

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ABSTRACT:
A Life Cycle Assessment, LCA, including modules A1-A3, Product, B4, Replacement and B6, Operational energy use, was performed for the environmental impacts on Climate change/Global Warming Potential. The LCA calculations were performed for three different cases, case 1 with centralized ventilation system, case 2 with centralized ventilation system with lover occupancy factor and case 3 with decentralized ventilation system.

The result from the LCA shows that the difference between the cases is small. Case 1 have a Global Warming Potential, GWP, of 122,81 kgCO_2-eq/m^2, case 2 have a GWP of 122,53 kgCO_2-eq/m^2 and decentralized system in case 3 has the lowest GWP of 120,75 kgCO_2-eq/m^2 calculated for Scenario 1 – NO mix. Case 3 is 1,7% lower than case 1. The main contributors to the difference in GWP are Air Handling Units and main ducts from the floors to the AHU, to outdoor air intake and exhaust. Where case 1 and 2 have less GWP for AHU than case 3. However, for ducts it is opposite.

KEYWORDS (separate with comma):
Life Cycle Assessment, Ventilation, Office building

Preface

This master thesis is the last part of the Master's Degree Programme in Energy and Environment in Buildings at OsloMet-Storbyuniversitetet. The thesis covers 30 of 120 ECTS credits and was performed during spring 2023.

The goal with this work was to investigate the contribution of Greenhous gas emissions from different Air treatment systems in an office building. The topic of this thesis is highly relevant and working with this thesis has even more open my eyes for the topic.

During this semester I have acquired lots of new knowledge, both professionally and about myself. I have been able to spend time working with relevant software and I have had the time to dig deep into the Life Cycle Assessment method.

I want to thank my internal supervisor, Peter Schild, for all support and motivation and I would like to thank Anders Liaøy and Christian Steneng for their support. I would also like thank the other students and supervisors in the Grønn VSS internal supervising team.

I would like to give a special thanks to my family for supporting me and for giving me the opportunity to perform this master's degree.

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Summary

To be able to achieve The United Nations Sustainable Development goal number 13 “Climate action” of limiting the global warming to 1,5°C and to be Greenhouse gas emission neutral in 2050, we need to take action. Reducing Greenhouse gas emission from buildings is one way of contributing to the Sustainable Development goal number 13. This master thesis aims to investigate the contribution of Greenhouse gas emission from Air treatment systems in office buildings by studying three different cases.

A Life Cycle Assessment, LCA, is a standardized way of calculating and reporting the environmental impact from a product or process. A LCA, including modules A1-A3, Product, B4, Replacement and B6, Operational energy use, was performed. The LCA study was limited to include the environmental impacts on Climate change/Global Warming Potential. The LCA calculations were performed for Air treatment system: 362 Duct network for air treatment, 364 Equipment for air distribution and 365 Equipment for air treatment according to NS3451:2022. For B6, Operational energy use, the LCA calculation is based on a yearly energy calculation.

A case building is used as a base in this Life Cycle Assessment. The building is an office building located in Oslo. It is developed three cases for the building:

- Case 1 represents an office building with centralized ventilation and with normal office work with most of the workers working inside the office all day.
- Case 2 represents an office building with centralized ventilation and where the use of the building is changed after 20 years. The first 20 years represents an office building where parts of the workers are working outside of the office with for example visiting customers or inspection. After 20 years the use of the building changes to a normal office work.
- Case 3 represents an office building with decentralized ventilation and with normal office work with most of the workers working inside the office all day.

A ventilation system is designed in REVIT for the cases and Air Handling Units is chosen from Air Handling Units suppliers design tool. An energy simulation is performed in IDA ICE to achieve yearly delivered energy for calculation of B6, Operational energy use. Finally, all parts are included in a LCA calculation for each case.

The result from the Life Cycle Assessment show that the difference between the cases is small. Case 1 have a Global Warming Potential, GWP, of 122,81 $kgCO_2\text{-eq}/m^2$, case 2 have a GWP of 122,53 $kgCO_2\text{-eq}/m^2$ and decentralized system in case 3 are having the lowest GWP of 120,75 $kgCO_2\text{-eq}/m^2$ calculated for Scenario 1 – NO mix. Case 3 is 1,7% lower than case 1. The main contributors to the difference are Air Handling Units and main ducts from the floors to the AHU and to outdoor air intake and exhaust. Where case 1 and 2 have less GWP for AHU than case 3. However, for ducts it is opposite.

This master thesis concludes that it is important to consider the floorplan and the layout of the building when choosing between a centralized and decentralized ventilation system while optimizing the impact on Global Warming potential. The thesis also concludes that it is important to include both embodied and operational emissions when performing a LCA for Air Handling Units.

Summary in Norwegian

For att oppnå De Forente Nasjoners, FN, bærekraftsmål nr 13 «Stoppe Klimaendringene» om at begrense den globale oppvarmingen til 1,5°C og at bli klimagass neutrale innen 2050 må vi handle nå. Att redusere klimagassutslipp fra bygg er en måte at bidra til FNs bærekraftsmål nr 13. Denne masteroppgave har som mål at undersøke bidraget til klimagassutslipp fra ventilasjons system i kontorsbygg med at studere tre ulike caser.

En livsløpsanalyse er en standardisert metode for at beregne og rapportere miljøpåvirkning av produkter eller prosesser. En livsløpsanalyse som inkluderer modulene A1-A3, Produkt, B4, Utskifting og B6, Energibruk i drift, er utført. Livsløpsanalysen er begrenset til at inkludere miljøpåvirkning fra klimagass utslipp/ Global oppvarming. Livsløpsanalysen er utført for system: 362 Kanaler for luftbehandling, 364 Utstyr for luftfordeling og 365 Utstyr for luftbehandling etter NS3451:2022. For modul B6, Energibruk i drift, er livsløpsanalysen basert på en beregning av årlig energibruk.

Livsløpsanalysen er basert på et case bygg. Bygget er et kontorbygg i Oslo. Det er utarbeidet tre caser for bygget:

- Case 1 representerer et kontorbygg med sentralt ventilasjonssystem og med normal kontors virksomhet der det fleste ansatte er på kontoret stor del av dagen.
- Case 2 representerer et kontorbygg med sentralt ventilasjonssystem og der bruken av bygget endres etter 20 år. I de første 20 årene har bygget en kontorvirksomhet der mange av det ansatte arbeider utenfor kontoret med at besøke kunder eller lignende. Efter 20 år endres bruken av bygget til en normal kontorvirksomhet.
- Case 3 representerer et kontorbygg med desentralt ventilasjonssystem men med en normal kontorvirksomhet der det fleste ansatte er på kontoret stor del av dagen.

Et ventilasjonssystem er tegnet i REVIT og Ventilasjons aggregater er valgt i en aggregatleverandør sitt verktøy for valg av aggregater. En energisimulering er utført i IDA ICE for at finne årlig levert energi til beregning av B6, Energibruk i drift. Til sist er alle deler satt sammen til en livsløpsanalyse for var case.

Resultatet av livsløpsanalysen viser at forskjellen mellom casene er liten. Case 1 har et Globalt oppvarmings potensial, GWP, på 122,81 $kgCO_2$-eq/m^2, case 2 har et GWP på 122,53 $kgCO_2$-eq/m^2 og det desentrale systemet i case 3 har det laveste GWP på 120,75 $kgCO_2$-eq/m^2 beregnet med Scenario 1 – NO miks. Case 3 har 1,7% lavere utslipp enn case 1. De største bidraget til forskjellen kommer fra aggregater og fra hovedkanaler fra etasjene til aggregat og videre til inntak og utkast. Case 1 og 2 har lavere GWP for aggregater enn case 3 men for hovedkanaler er det omvendt.

Konklusjonen fra master oppgaven er at det er viktig at ta hensyn til byggets plantegning og utforming når beslutning om et sentralt eller desentralt system skal velges utfra målet at optimalisere miljøpåvirkningen fra ventilasjonssystemet. Oppgaven konkludere også med at det er viktig at inkludere både bundne og ikke bundne utslipp når det skal utføres en livsløps analyse for ventilasjons aggregater.

Content

Glossary

AHU	Air Handling Unit
CO_2	Carbon Dioxide
EPD	Environmental Product Declaration
ESL	Estimated Service Lifetime
GHG	Greenhouse gas
GWP	Global Warming Potential
HVAC	Heating Ventilation and Air Conditioning
LCA	Life Cycle Assessment
PCR	Product Category Rule
ReqSL	Required Service Life
RSL	Reference Service Lifetime
SFP	Specific Fan Power
TEK17	Byggteknisk forskrift
VAV	Variable Air Volume system
VVS	Varme-, ventilasjon- og sanitærteknikk

1 Introduction

This chapter introduces the background and the research questions for this master thesis, it also presents limitation and the structure of the thesis.

1.1 Background

The United Nations, UN, Sustainable Development goal number 13 “Climate action” states that the world needs to take action to reach the goal of limiting the global warming to 1,5°C and to be Greenhouse gas emission neutral in 2050 [1]. In the EU, buildings are contributing with 36% of the CO_2 emissions and 40% of the energy consumption [2]. Reducing Greenhouse gas emission from buildings is one way of contributing to the Sustainable Development goal number 13. The goal of the research group Grønn VVS is to develop methods for design and building of HVAC installations that reduces the Greenhouse gas emission from HVAC installations with 50% before 2025 [3].

According to the Grønn VVS project at least 20% of the total Greenhouse gas emission from buildings comes from HVAC installations [3]. In 2022 two master thesis at OsloMet, connected to Grønn VVS, showed that Air treatment systems have the largest contribution to the Greenhouse gas emission from HVAC installations [4] [5]. This master thesis will look further on the Air treatment system and its Greenhous gas emission contribution from buildings.

To be able to work with reduction of Greenhouse gas emission and Global Warming Potential we need a way to calculate and compare the emissions. Life Cycle Assessment, LCA, is a method that describes a standardized way to calculate and report the environmental impacts of a product or process [6] and will be the basis for this master thesis.

The design of an Air treatment system and the choice of components contributes to the amount of Greenhouse gas emission from the system. This master thesis aims to investigate if the choice between a Centralized air treatment system or a Decentralized air treatment system has an impact on Global Warming Potential. The thesis will also investigate the impact of the Air Handling Unit selection regarding Global Warming Potential.

1.2 Research questions

This master thesis aims to answer the following questions:

- Is there any difference in Global Warming Potential from a Centralized air treatment system or a Decentralized air treatment system for an office building?
- Which parts of the systems are contributing to the difference in Global Warming Potential?
- How does the choice of Air Handling Unit regarding dimension and Specific Fan Power contributes to the Global Warming Potential?
- Is it a significant impact on the Global Warming Potential if the building uses a smaller Air Handling unit and lower air volume during a part of the lifetime?

1.3 Study limitations

The nature of a master thesis gives limitations in time available for the student to answer the research questions fully. In order to be able to answer the questions during the available time the following limitations are defined:

- The LCA study includes module A1-A3, Product, B4, Replacement and B6, Operational energy use.
- The LCA study is limited to include the environmental impacts on Climate change/Global Warming Potential.

- LCA calculations is performed for Air treatment system: 362 Duct network for air treatment, 364 Equipment for air distribution and 365 Equipment for air treatment according to NS3451:2022 [7].
- For B6, Operational energy use, the LCA calculation is based on a yearly energy calculation.
- Cost impact analysis is not included in this thesis.

1.4 Structure of the thesis

The work in this thesis is based on a case building and the investigation is structured in three cases. The case building and the three cases are described in chapter 3.

Chapter 2 present a theoretical background and a literature review. Chapter 3 describes the method used for design of the system, energy calculation and LCA calculation in addition to the description of the case building and the three cases. In chapter 4 the result is presented and discussed. The conclusion and recommendation for further work is presented in chapter 5.

2 Theoretical background

Chapter 2 will present a theoretical background for Life Cycle Assessments and this chapter will also present some earlier work on LCA for ventilation systems. An investigation of status for Environmental Product Declaration, EPD, for Air Handling Units, AHU, is also presented.

2.1 Life Cycle Assessment, LCA

With an increased focus on sustainability and sustainable buildings, the need for methods and tools to calculate and compare the environmental impacts occur. The methodology of Life Cycle Assessment is used in this master thesis and described in this chapter.

2.1.1 What is Life Cycle Assessment, LCA

Life Cycle Assessments, LCA, is a standardized way of calculating and reporting environmental impacts from product or process. A LCA calculates the quantity of emissions to nature and the extraction from nature during the whole life cycle of the product or process included in the study. To be able to work with reduction of the impact it is important to be able to determine the impacts. [6]

A LCA study can help identify opportunities for improvements of the environment impacts for a product. It can be a support for decision making when priority and planning a product and it can also assist in marketing of a product. A LCA can also be a support when selecting of indicators for environmental performance. [8]

In a LCA, all quantities of raw materials, waste outputs and the emissions to air, land and water is accounted for. All the emissions are summarised into environmental impact categories. In current LCA practise the emissions is summarised into five to eight primary categories along with consumption and emission for water, energy, and waste. The most common used impact categories are: [6]

- Acidification
- Climate Change/Global Warming
- Eutrophication
- Ozon Depletion
- Photochemical Ozone Creation/Smog

The impact category Climate Change includes the impact of global warming, the increase of global average temperature of the Earth's surface and other significant change to climate. The impact is reported in CO_2-eq as Global Warming Potential, GWP, or Greenhous gas emissions, GHG, or carbon footprint. The Greenhouse gas emissions calculated in CO_2-eq includes emissions from carbon dioxide, CO_2, water vapor, H_2O, methane, CH_4, and other gasses that is working on climate impact. The greenhouse gases are trapping the heat to Earth and function like a greenhouse trapping heat inside the glass. [6]

2.1.2 How to perform an LCA calculation

There are several standards in connection with performing a LCA calculation. Byggforskserien 470.101 - *Livsløpsvurdering (LCA) av byggevarer og bygninger Innføring og begreper,* defines:

- NS-EN ISO 14040 – *Environmental management Life cycle assessment Principles and framework* and NS-EN ISO 14044 - *Environmental management Life cycle assessment Requirements and guidelines* as general standards for life cycle assessments
- NS-EN 15978 *Sustainability of construction works Assessment of environmental performance of buildings Calculation method* as a standard for the buildings environmental impact [9].

The Norwegian standard NS 3720:2018 *Method for greenhouse gas calculations for buildings* defines a method for calculation of greenhouse gases for a whole building, part of buildings or building components. It is built on NS-EN 15978 however it is limited to only calculate Greenhouse gas emissions. The standard defines a method for a cradle to grave calculation, but it can also be used for calculations of greenhouse gas emissions for parts of the lifecycle of a building. It can be used for all phases of the building process. [10]

2.1.3 LCA framework

The LCA framework defined in NS-EN ISO 14040 describes the phases of a LCA. The framework contains of four phases as described in Table 1. A LCA is an iterative process and it maybe need to go back and forward in the process when data and information is collected [8].

Table 1. The LCA framework defined in NS-EN ISO 14040 – Environmental management Life cycle assessment Principles and framework [8].

LCA phase	**Description**
Goal and scope definition	This phase shall describe the intended application of the study. The reason of why the study is performed and who the study is made for. It shall also describe if the results are intended to be public. The scope of the study shall be defined and shall describe the product to be included, the functional unit, system boundaries of what's included in the study and allocation procedures. The scope definition shall also define which impact categories that is included in the study as well as data requirements, assumptions, limitations, and data quality. Also, the way of critical review and how to report the results shall be included in the scope definition.
Inventory analysis	In this phase all data of material and energy is collected and calculated into inputs and outputs of the system. Allocations may be done in this phase to assign correct amount of emissions to the products.
Impact assessment	This phase is evaluating the potential environmental impact of the results in the inventory analysis.
Interpretation	This phase interprets the result of the impact assessment and reports the results. It is important that the result is consistent with the defined goal and scope.

2.1.4 LCA stages and modules

The life cycle of a building is divided into different stages and modules as showed in Table 2. The stages and modules are used for organization of the assessment and corresponds to the information modules in an EPD. The modules described in Table 2 are a translation of the modules in NS 3720:2018. [10]

Table 2. Information about a building's lifetime with stages and modules from NS 3720:2018 Method for greenhouse gas calculations for buildings and with translation into English with guidance of the CIBS report Embodied carbon in building services: a calculation methodology [10] [11].

Information of the assessment of the building					
Information of the building lifetime					
Stage	A		B	C	D
	Product	Construction	In use	End of life	Beyond the life cycle
Module	A1: Material extraction A2: Transport to factory A3: Manufacturing	A4: Transport to site A5: Construction	B1: Use B2: Maintenance B3: Repair B4: Replacement B5: Refurbishment of the building B6: Operational energy use B7: Operational water use B8: Transport in use	C1: Deconstruction C2: Transport C3: Waste processing C4: Disposal	D: Reuse, recovery, recycling

NS 3720:2018 describes a method for a cradle to grave LCA. A cradle to grave LCA is calculating the total environmental impact of the building and includes all modules except module D. Other way to perform a LCA is [6]:

- A cradle to gate LCA includes module A1, A2 and A3.
- A gate to gate only incudes module A3.
- A cradle to grave as described above.
- A cradle to cradle includes all modules.

Embodied carbon is Greenhouse gas emissions from module A1-A3, Product, A4-A5, Construction, B1-B5, In use, and C1-C4, End of life. Operational carbon is Greenhouse gas emissions from the buildings energy and water used during the operational lifetime in module B6, Operational energy use, and B7, Operational water use. [11]

2.1.5 Generic data vs data from EPD and PCR functionality

An Environmental Product Declaration, EPD, is a document that describes the environmental profile to a product or service in a standardized and objective way. An EPD is based on a LCA according to ISO 14040 and ISO 14044 and the EPD shall be made after ISO 14025. A 3rd party verified EPD ensures that the content is objective, comparable, credible, and addable. [12]

EPDs are not available for all products and services therefore other data, with less accuracy, need to be included in the LCA. Such data can be data based on earlier studies of equivalent products or average values of from a product group. Generic data can be collected from databases or from other products with EPD. [13]

A Product Category Rule, PCR, is a document that ensure that the producer of an EPD have listed all substances with significant environmental impact included in the product in the EPD. The PCR also makes it easier for the costumer to compare EPDs from several product, within the same category. The PCR is developed in collaboration with companies and stakeholders within the same business. It is sent on a consultation round and finale approved by the Næringslivets Stiftelse for Miljødeklarasjoner at Verifikasjonskomiteen. [14]

2.2 TEK17 regulation for LCA

TEK17 §17-1 *Klimagassregnskap fra materialer* states that all new and rebuilt residential house and commercial building shall perform a Greenhous gas emissions calculation. The calculation shall be according to the Norwegian standard NS 3720:2018 however the calculation shall at least include module A1-A4, B2 and B4. The regulation defines which building elements according to NS 3451:2022 that needs to be included and building elements category 3, HVAC installation, is not a part of the included scope in the calculation. [15]

The TEK17 §17-1 *Klimagassregnskap fra materialer* regulation states that the calculation shall be performed over 50 years. Waste from building site shall be included in the calculation in module A5. Data used in the calculation shall be from 3rd party verified and lifecycle-based sources such as EPDs however when data is not available the regulation opens for use of generic data with a compensating factor of 25%. [15]

The regulation TEK17 §17-1 *Klimagassregnskap fra materialer* is valid from 1 July 2022 but with a transitional rule until 1 July 2023 [16].

2.3 Available research on LCA for ventilation in office buildings

A short literature review is performed for investigate what have been done before on LCA for ventilation in office buildings.

The scientific database Scopus, Science direct and Google Scholar have been used for the search of articles. Scopus give 12 articles, Science direct 4 and Google scholar 5. For search in Scopus and Science direct was limited to search only in Title, Keywords and Abstract. Google scholar does not have the opportunity to search in Title, Keywords and Abstract, therefore the search in Google scholar was limited to only title. All 4 articles in Science direct where duplicates with articles in Scopus. The search was performed with the following search string with some modification to meet the different database:

(("LCA" OR "klimagass") AND ("ventilation" OR "ventilasjon") AND ("office building"))

All articles were screened to select the article that is interesting for this thesis. The articles were screened for the following criteria:

- Include ventilation system.
- Published in Europe, North America, Australia, or Nya Zeeland.
- Published in 2018 or later.

4 articles were found to be interesting from the search. Two article of special interest that was found outside the search is added to the result. The result of the search is presented in Table 3.

Table 3. List of articles to review.

Author	Article	Country	Year of publish	Source
D. Ramon et al.	Dynamic modelling of operational energy use in a building LCA: A case study of a Belgian office building	Belgium	2023	[17]
M. Rabani et al.	Life cycle analysis of GHG emissions from the building retrofitting: The case of a Norwegian office building	Norway	2021	[18]
C. Kiamili et al.	Detailed assessment of embodied carbon of HVAC systems for a new office building based on BIM	Switzerland	2020	[19]
P. Ylmén et al.	Life cycle assessment of an office building based on site-specific data	Sweden	2019	[20]
Wiik et al.	Klimagasskrav til materialbruk i bygninger - ZEN report No.24	Norway	2020	[21]
Wiik et al.	Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre	Norway	2018	[22]

Ramon et al. (2023) - Dynamic modelling of operational energy use in a building LCA: A case study of a Belgian office building [17]

The authors are looking at changes in the operational phase due to climate change. They are investigating the impacts of variations in yearly operational energy consumption due to climate change. They are also investigating the impact of the expected change in energy mix due to climate mitigation. The result of the study is presented in Life cycle environmental cost, €/m^2, and includes several impact indicators, and therefore not comparable for this thesis.

Rabani et al. (2021) - Life cycle analysis of GHG emissions from the building retrofitting: The case of a Norwegian office building [18]

The article is investigating the embodied and operational emissions for different retrofitting scenarios for a typical Norwegian office building. The LCA study is performed in OneClick LCA and are looking at Greenhouse Gas emissions for module A1-A3, Product, A4, Transport to construction site, A5, Construction and installation work, B4-B5, Replacement and retrofitting, B6, Operational energy use, and C1-C4, End of life service. The energy used for calculation of B6 was calculated in IDA ICE in a previous study. The study is done over a 60-year period. The study concludes with that the net total emissions could be reduced up to 52% from 1336 kg CO_2-eq/m^2 for the reference case to 637 kgCO_2-eq/m^2 for the best case.

In the study, embodied CO_2-eq emissions is calculated for the 10 resources with largest environmental impact in the reference building. Ventilation represents approximately, read out of figure, 27 kgCO_2-eq(kg/m^2) for A1-A3, 0,4 kgCO_2-eq(kg/m^2) for A5 and 27 kgCO_2-eq(kg/m^2) for B4-B5, in total 54,4 kgCO_2-eq(kg/m^2). Module C1-C4 for ventilation represents a marginal part of the CO_2-eq emissions for the reference building in this study.

The study presents results from calculation of embodied CO_2-eq from material for HVAC installations for the 4 cases and the reference case presented in Figure 1.

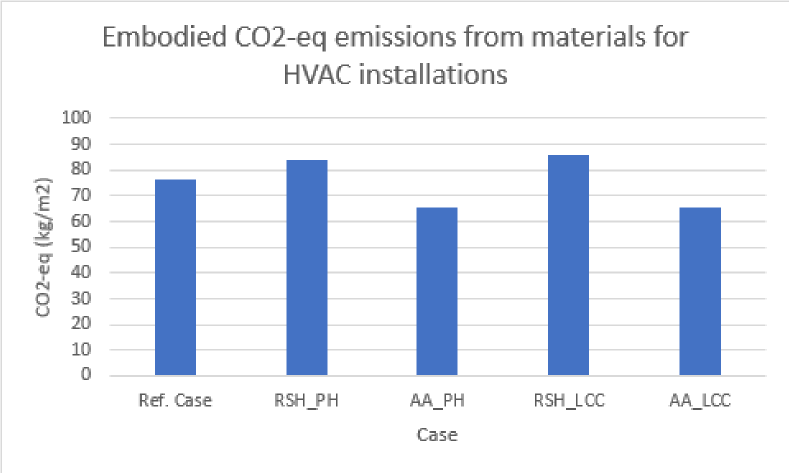

Figure 1. Embodied CO_2-eq from material for HVAC installations from the article Life cycle analysis of GHG emissions from the building retrofitting: The case of a Norwegian office building. Data presented in the figure is collected from table in the article [18].

Kiamili et al. (2020) - Detailed assessment of embodied carbon of HVAC systems for a new office building based on BIM [19]
The article presents a detailed life cycle assessment for HVAC systems based on a building information model, BIM, for a newly built office building in Switzerland. The study investigates CO_2-eq emissions for the embodied impact in A1-A3, B4, C3-C4 and operational impact in B6, Operational energy use, over a 60-year period. The article also presents a method for performing a complete LCA using BIM. The study concludes that the total embodied impact for HVAC systems is 183 kg CO_2-eq/m^2. It also states that the Air Handling Unit, AHU, stand for 21,9 kg CO_2-eq/m^2 and that the filter to mechanical equipment stands for 11% of the total replacement impact during the use phase.

Ylmén et al. (2019) - Life cycle assessment of an office building based on site-specific data [20]
The authors have performed a LCA for a whole office building for five environmental impact categories. Site-specific data was collected during production of the building and included data on building products, transport, machinery, energy use etc. The result is presented in the functional unit 1m^2 A_{temp} and the time frame is 50 years. The study includes module A1-A5, B4, B6 and C1-C4. The results for HVAC installation on Global Warming Potential is approximately 145 kg CO_2-eq/m^2 A_{temp} (read out of figure). The article also highlights the impact of 14-32% from technical installation in four of five environmental impact categories.

Wiik et al. (2020) - Klimagasskrav til materialbruk i bygninger - ZEN report No.24 [21]
The report has developed benchmark values for Greenhouse gas emissions from material use in buildings. The report has collected data from over 130 Norwegian building projects during 2009-2020. The report shows a decrease in calculated emissions from 2012/2013 until 2019. It has been a development in use of standards and tools for calculation in this period. The report is focusing on Greenhouse gas emissions from module A1-A3 and B4 and they are presenting the result in kg CO_2-e/m^2 and kg CO_2-e/m^2/year.
Most of the studies included in this work reported data on building body, building elements category 21-29, but only a few studies reported on other building parts such as HVAC. Among the reported studies, building body category 21-29 counts for 51% of the Greenhouse gas emissions and emissions from HVAC, telecom, automatic and technical installation, category 31-69, stands for 21%. It is assumed that emissions from category 31-79 is underreported. The results for all building categories show an interquartile range of 240-492 kgCO_2e/m^2 or 4,0-8,2 kgCO_2e/m^2/year and a median of 324 kgCO_2e/m^2 or 5,4 kgCO_2e/m^2/year in the as-built phase. The result for office buildings, presented in Figure 2, shows an interquartile range of 3,1-10,0 kgCO_2e/m^2/year and a median of 5,0 kgCO_2e/m^2/year.

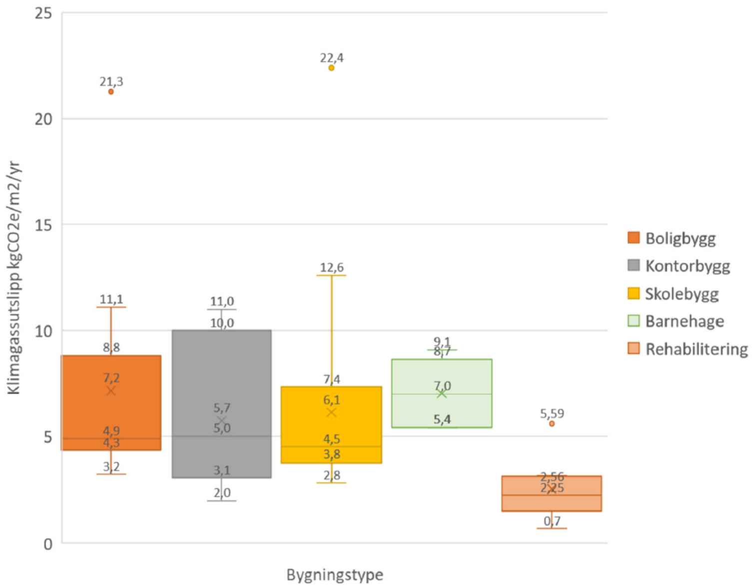

Figure 2. Results from calculation of Greenhouse gas emissions for different building types from the report Klimagasskrav til materialbruk i bygninger - ZEN report No.24 [21].

Wiik et al. (2018) - Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre [22]
The article is looking at the methodology of and results for calculation of Greenhous gas emissions from seven ZEB cases studies. The result and the methodology are present, evaluate and discuss to extract design drivers and lesson learnt. The calculation has been done with the ZEB excel based LCA tool. The functional unit was 1m^2 heated floor area (BRA) and the study were done for 60 years. The study included module A1-A3, A4-A5, B1-B7 and C1-C4.
Total GHG emissions in A1-C4 was 12,80 kgCO_2/m^2/yr and 9,43 kgCO_2/m^2/yr for the two office buildings cases in the study. For building elements category 36, Ventilation and air conditioning, the two offices building are having a GHG emission of 0,43 kgCO_2/m^2/yr and 0,26 kgCO_2/m^2/yr.
The report highlights the importance of having an equal understanding of system boundaries and data source to get comparable results. The report also highlights the benefits and risk of focusing on only Global Warming Potential and it states that the main challenges in GHG emissions calculations lies in data management.

2.4 Building elements

When performing a LCA according to NS 3720:2018 *Method for greenhouse gas calculations for buildings* all included object shall be classified and coded according to NS 3451:2022 *Table of building elements and table of codes for systems in building with associated outdoor areas* [10].

Codes from NS 3451:2022 of interest in this master's thesis is presented in Table 4.

Table 4. Codes for ventilation objects from NS 3451:2022 Table of building elements and table of codes for systems in building with associated outdoor areas [7].

Code	Name
362	Duct network for air treatment
364	Equipment for air distribution
365	Equipment for air treatment

2.5 Centralized and decentralized ventilation

Where to place the Air Handling Units needs to be decided early in the project. The choice of placing the AHU in a larger technical room, centralized solution, or spread out in the building close to the office areas, decentralized solution, need to be considered. The two different solutions are illustrated in Figure 3. The choice of solution creates limitations for how the spaces in the building can be disposed. There is no clear quality difference between the two solutions however they have some advantages and disadvantages. [23]

Advantages with centralized ventilation are less need for intake and exhaust points and easier to get an optimal placement of the intake and exhaust points. It is also easier to get access for maintenance and there is no need for coordination with user of the building during maintenance. It is also an advantage that the AHU can be placed in basement and roof area. Disadvantages with centralized ventilation are more need for technical shafts and risk of odors to be transferred between areas. [23]

Advantages with decentralized ventilation are that it is often only one user of the AHU which makes it easier to separate cost and to make individual adjustment on setpoint. A decentralized solutions have less need for technical shafts. One of the disadvantages with decentralized ventilation is a significant use of floor area close to the office area which both occupy space and can create noise in the office area. Other disadvantages are difficulty in placing intake and exhaust points and that decentralized AHU needs a larger area with low ceiling around the technical room. Also, maintenance needs to be coordinated with the user of the office area. [23]

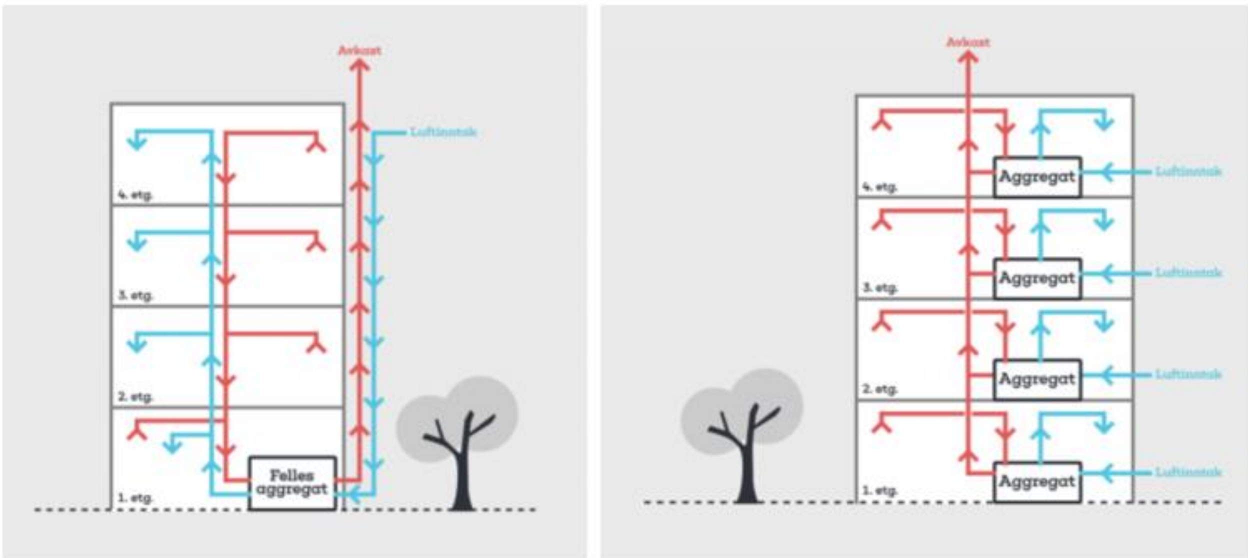

Figure 3. Illustration of centralized ventilation solution to the left and decentralized ventilation solution to the right [23].

2.6 Air Handling Units, AHU

An Air Handling Unit, AHU, is one of the largest components in a ventilation system. The main purpose of the AHU is to deliver good air quality by supplying the building with fresh air and extracting used air from the building. The AHU can also be designed to heat or cool the supply air with a heat exchanger, heater or cooler. An AHU contains of several different components such as fans, heater, cooler, filters and heat exchanger and large AHU are often module based with different components to meet the demand of the individual building.

2.6.1 Suppliers and EPD status

It is several suppliers of AHU for office buildings in the Norwegian market. An investigation of the most common supplier's internet homepage and epd-norge.no shows that only Swegon AS [24] and Ventistål AS/FläktGroup Sweden AB [25] has EPDs available for their AHU. Table 5 present suppliers included in the search and the result with EPD numbers for available EPDs.

Table 5. Investigation of the most common Norwegian AHU suppliers shows that Swegon AS and Ventistål AS/FläktGroup Sweden AB have EPDs. [26] [27] [28] [29] [30] [24] [31] [25] [32]

Supplier	EPD	EPD nr:	Product
Covent AS	No		
Exhausto AS	No		
Flexit AS	No		
IV Produkt AS	No		
Nilan Norge AS	No		
Swegon AS	Yes	S-P-05063	Gold RX 011/012 - Silver C RX 011/012
Systemair AS	No		
Ventistål AS/FläktGroup Sweden AB	Yes	NEPD-3290-1935-NO	eQ50
Östberg Norge AS	No		

A comparison of GWP for the two AHU with EPDs is presented in Table 6 and Figure 4. The EPD for eQ50 is most conservative regarding GWP and the Gold RX 011/012 – Silver C RX 011/012 has 20% lower GWP than eQ50 [24] [25]. It is important that the EPDs are having the same system boundaries and includes the same function when comparing EPDs for products. In this case it is not possible to read out of the EPD for Gold RX 011/012 – Silver C RX 011/012 if the AHU includes a cooling coil or not which will influence the material percentage [24]. It looks like eQ50 includes a cooling coil in the AHU when analysing the figure of the AHU on page 3 in the EPD for eQ50 [25].

The EPD for eQ50 declares that CEN Standards 15804 serves at core PCR together with NPCR030 v1 Part B for ventilation components (05/2021) [25]. For Gold RX 011/012 – Silver C RX 011/012 the EPD declares PCR 2019:14 Construction products Version 1.11 date 2021.02.05 as PCR [24]. Since the two EPDs are not based on the same PCR and may not include the same functions they cannot be compared with full accuracy. Despite the differences in setup for the EPDs it is chosen to compare the EPDs, in Table 6 and Figure 4, and the GWP for each module are divided by the mass of the AHU to get a comparable unit.

Table 6. A comparison of GWP for the AHU eQ50 from FläktGroup AB/Ventistål AS and Gold RX 011/012 – Silver C RX 011/012 from Swegon AS [25] [24].

	Unit	A1-A3	A4	A5	C1	C2	C3	C4	Total excl.	D
eQ50 - GWP	kg CO2-eq	1,91E+04	4,24E+02	MND	3,85E+00	7,96E+01	1,25E+02	9,13E-01	1,97E+04	-6,83E+03
eQ50 - GWP/kg	kg CO2-eq/kg	6,45E+00	1,43E-01	MND	1,30E-03	2,69E-02	4,22E-02	3,08E-04	6,67E+00	-2,31E+00
Gold RX 12 - GWP	kg CO2-eq	2,46E+03	1,65E+01	6,60E+01	1,66E-01	4,38E+00	3,75E+01	6,00E+00	2,59E+03	-8,39E+02
Gold RX 12 - GWP/kg	kg CO2-eq/kg	5,04E+00	3,38E-02	1,35E-01	3,40E-04	8,98E-03	7,68E-02	1,23E-02	5,31E+00	-1,72E+00

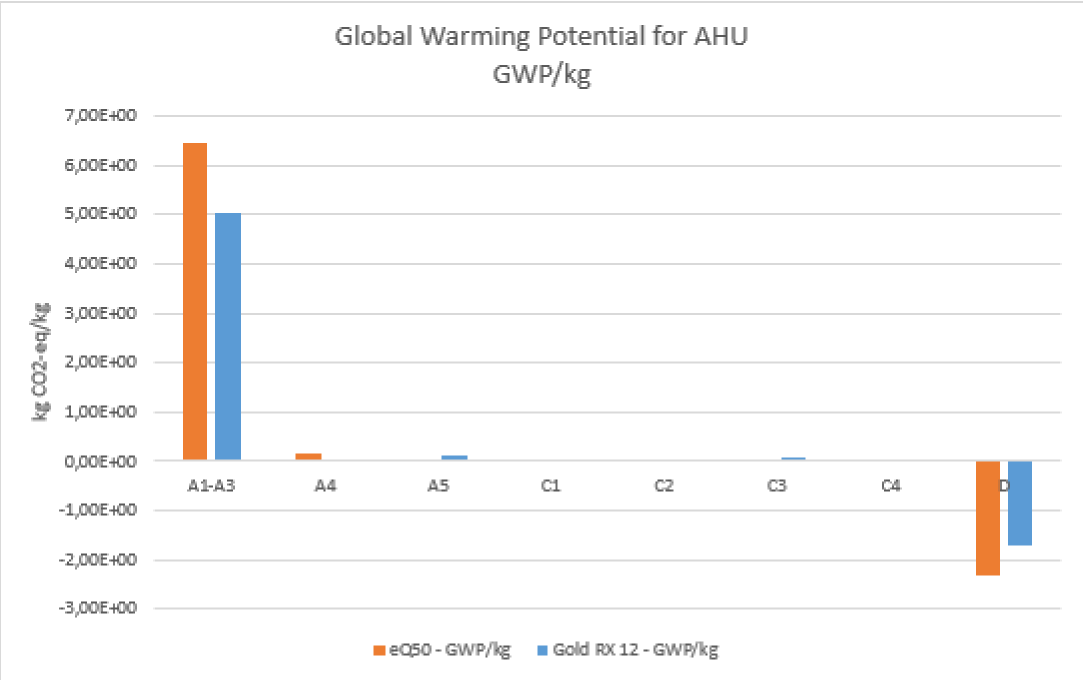

Figure 4. A comparison of GWP for the AHU eQ50 from FläktGroup AB/Ventistål AS and Gold RX 011/012 – Silver C RX 011/012 from Swegon AS [24] [25].

2.6.2 LCA for Air Handling Units – previous work

When analyzing the literature in Chapter 2.3 it was only possible to discover which data that have been used for calculating the GWP for AHU in one of the articles. Rabani et al. declares that generic data from One Click LCA have been used [18]. None of the other five articles declared which data that have been used for AHU. Kiamili et al. declares that AHU represents 21,9 kg CO_2-eq/m^2 [19].

3 Methodology

This chapter describes the methodology for calculating the Global Warming Potential, GWP, for the ventilation systems. The chapter starts with describing the case building and the three cases used in this thesis. Next section describes the design of the ventilation system with air volume calculations, design in REVIT and the process for choosing Air Handling Units, AHU. Three AHU are selected for each case for evaluation and the evaluation process results in one AHU for each case used in further calculation of the GWP. The GWP is calculated and discussed for all nine AHU, however only one AHU is used for each case in the GWP calculation for cases.

Chapter three also describes the procedure and model for energy simulation in IDA ICE. The result from energy simulation is used for calculation of the GWP. Chapter 3.5 describes the method for the Life Cycle Assessment for all parts included in this thesis.

3.1 Case study building – Bøkkerveien 1-3

Bøkkerveien 1-3 is a new commercial building project developed by Höegh Eiendom AS. It is located between Økernveien and Haslevangen downtown Oslo, Norway, and in the Hasle line development area. The area is a former industrial area that today is used for parking. The project is developing three commercial building with a common first floor and with a total gross area of approximately 30 000m^2. The project is in an early phase and changes to the project will occur. [33]

All three building are having different theme, building A are focusing on reuse and shared use, building B is a Future built plus house and building C are focusing on health, indoor climate, and well-being. The project has a goal of 50% reduction of greenhouse gas emissions and an ambition of the Norwegian Energimerke class A and BREEAM NOR Excellent. [33]

The 3rd floor of building C is used in this master's thesis. The 3rd floor contains of three different areas for office rental. All three areas contain of open landscape office, meeting rooms, kitchen, and toilets. To limit the work with developing of a ventilation system the layout of the 3rd floor is used 3 times to simulate results for a 3-floor building. The layout for the 3rd floor has an open ceiling to the 4th floor which is neglected in this thesis. A draft of the 3rd floorplan used in this thesis is showed in Figure 5. Since the project, Bøkkerveien 1-3, is in an early phase all floorplans are drafts and changes will occur.

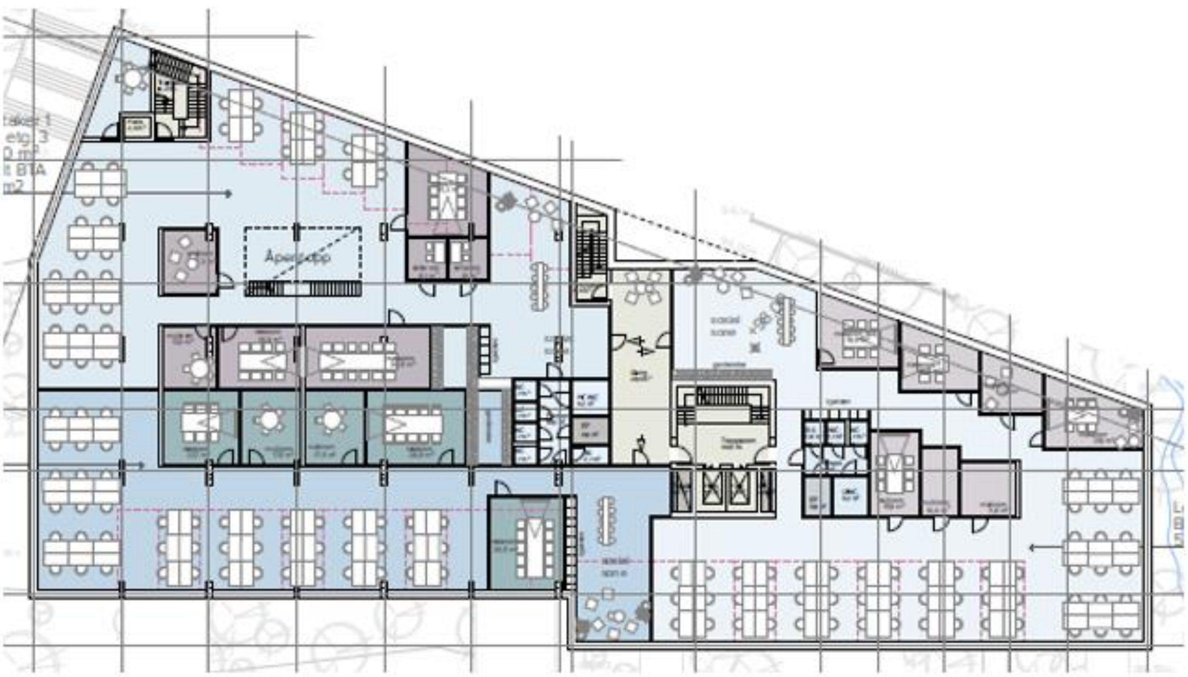

Figure 5. Draft of the 3rd floor used in this thesis. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

3.2 Design case

Three different design cases are developed and calculated in this thesis. The cases are developed to represent different scenarios of design and use of the building and to be able to compare different strategies for design of ventilation systems.

- Case 1 represents an office building with centralized ventilation and with normal office work with most of the workers working inside the office all day.
- Case 2 represents an office building with centralized ventilation and where the use of the building is changed after 20 years. The first 20 years represents an office building where parts of the workers are working outside of the office with for example visiting customers or inspection. After 20 years the use of the building chance to a normal office work.
- Case 3 represents an office building with decentralized ventilation and with normal office work with most of the workers working inside the office all day.

Table 7 describes the design criteria for the different cases.

Table 7. Description of design cases.

Case 1	Centralized ventilation Local heating and cooling Air volume according to TEK17 regulations Occupancy factor, OFz, 99 percentiles of Halvorsen high curve =0,907 [34] [35] Simultaneity Factor, S=0,944 Design of AHU according to $Q_{DCV\ high\ OF}$ Design of main duct according to $Q_{DCV\ high\ OF}$
Case 2	Centralized ventilation Local heating and cooling Air volume according to TEK17 regulations *First 20 years, low occupancy factor:* Occupancy factor, OFz, 99 percentiles of Halvorsen low curve =0,699 [34] [35] Simultaneity Factor, S=0,818 Design of AHU according to $Q_{DCV\ low\ OF}$ Design of main duct according to $Q_{DCV\ high\ OF}$ *After 20 years, high occupancy factor:* Occupancy factor, OFz, 99 percentiles of Halvorsen high curve = 0,907 [34] [35] Simultaneity Factor, S=0,941 Design of AHU according to $Q_{DCV\ high\ OF}$ Design of main duct according to $Q_{DCV\ high\ OF}$
Case 3	Decentralized ventilation Local heating and cooling Air volume according to TEK17 regulations Occupancy factor, 1 Simultaneity Factor, S=1 Design of AHU according to Q_{max} Design of main duct according to Q_{max}

3.3 Design of ventilation system

A ventilation system is designed for the 3rd floor in building C on Bøkkerveien 1-3. The designed ventilation system is the basis for calculation of the Global Warming Potential, GWP.

As described in Chapter 3.1, the layout of the 3rd floor is used however the opening in the ceiling to the 4th floor is neglected. Air volume calculation and work in REVIT is done for the 3rd floor and later multiplied by three to simulate a 3-floor building.

The ventilation system is designed as a Variable Air Volume system, VAV, with temperature as regulation factor. A VAV system regulates the airflow after the demand [36].

Fire safety, sound regulation, distance between components such as VAV dampers and bends, and throw length on air supply units are not considered when designing the system. Sound attenuators are included in the system design in REVIT for the purpose of including them in the GWP calculations. Air supply for stairs and elevators are not included in the design. These are all aspects to consider when designing a ventilation system but due to limitation of time and that the goal of the thesis is to compare centralized and decentralized system they are not considered. Focus during the design process is to get the quantity for further LCA calculations.

3.3.1 Air volume calculations

When calculating the air supply volume, there are several aspects that needs to be taken into account, such as local regulation, the need for heating and cooling through the ventilation systems, the use of the building and the future use of the building. Since heating and cooling is designed to be solved with local solutions, the air supply is designed according to The Norwegian Byggteknisk forskrift, TEK 17 regulation.

The Norwegian Byggteknisk forskrift, TEK17, regulate the dimension of air volume in commercial building in §13-3 *Ventilasjon i byggverk for publikum og arbeidsbygning*. TEK17 §13-3 define the air volume to be calculated from [37]:

A. Emission from people in low activity: 26m^3/(h/person).
B. Emission from material, product, and installation, when low emission material is used: 2,5m^3/(h/m^2) when the room is in used and 0,7m^3/(h/m^2) when the room is not in use.
C. Emission from activity and process in the building. Predefined values for exhaust air in special room according to Table 8.

Table 8. Predefined value for exhaust air from TEK17 [37].

Room	**Exhaust air volume**
Bath/shower	54 m^3/(h/shower)
WC	36 m^3/(h/WC)
Elevator	30 m^3/(h/m^2)
Basement	2,5 m^3/(h/m^2 gross net area)
Garage long time parking	3 m^3/(h/m^2 gross net area)
Garage short time parking	6 m^3/(h/m^2 gross net area)

Number of persons and area of the room is calculated from the floorplan for the 3rd floor. Low emission material is a precondition.

The total maximum fresh air volume, Q_{max} is calculated from the largest value of A+B or C [37], which also can be named Q_{CAV}. The total minimum air volume, Q_{min} is calculated from the sum of all B when the building is in use and the night ventilation air volume, Q_{night} is the sum of all B when the building is not in use.

The use of the building is considered when calculating the fresh air supply for a VAV ventilation system. After calculation the air volume demand from TEK17 regulation, Formula 1, 2 and 3 from the report, *Demand controlled ventilation for office cubicles – can it be profitable?* [38], is used to find the demand controlled air volume Q_{DCV}.

$$Q_{DCV} = Q_{CAV} * OF + Q_{CAV} * b(1 - OF) = Q_{CAV}(OF + b - b * OF) \left[\frac{m^3}{h}\right] \quad (1)$$

$$S = OF + b - b * OF \qquad [-] \quad (2)$$

$$b = \frac{Q_{min}}{Q_{max}} \quad [-] \quad (3)$$

Q_{DCV}	Demand controlled air volume	m³/h
Q_{CAV}	Constant air volume	m³/h
Q_{min}	Minimum air volume	m³/h
Q_{max}	Maximum air volume	m³/h
OF	Occupancy factor	-
b	Minimum ventilation rate	-
S	Simultaneous factor	-

In the PhD report, *Occupancy Pattern in Office Buildings*, Halvarsson measured the Occupancy factor zone, OF_Z, in several Norwegian office buildings. OF_Z is a factor that describes the ratio of occupied sub zone and the total number of sub zones [34]. Halvarsson's work is done for cellular office but in lack of other data Halvarsson's work is used, even though this building has an open floor plan. The OF_Z from Halvarssons PhD report is converted into presence duration curves by the supervisor of this master's thesis. The 99 percentiles of the high versus low OF_Z curve is used for OF in Formula 1 and 2 to find the air volume for a DCV ventilation system for each case. The 99 percentiles are found by interpolating between 80% and 100% cumulative % working hours (0600-1800) from Figure 6.

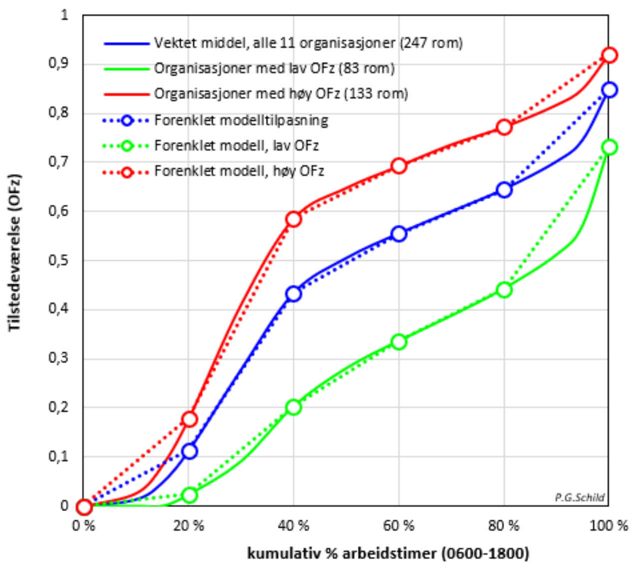

Figure 6. Occupancy factor, OFz, for cumulative % working hours (0600-1800) used for calculation of air volume. The graph is developed by Peter Schild based on data from Halvorssons PhD report [35] [34].

Calculations on room level is equal for all cases and are made for one floor, calculations on room level are presented in Appendix A. Calculation of total air volume are made with three floors and separate for all cases, with the condition for each case presented in Table 7. Appendix B present calculation of total air volume for each case and Table 9 shows a summary of air volume.

Table 9. Calculated air volume for each case.

	Room level			AHU level						
	TEK 17 regulations			Case 1		Case 2			Case 3	
				Ofz:	0,907068	Ofz:	0,699229	0,907068	Ofz:	1
				S:	0,9436573	S:	0,8176488	0,9436573	S:	1
	Qmin [m3/h]	Qmax [m3/h]	Qnight [m3/h]	Qmin [m3/h]	QDCV [m3/h]	Qmin [m3/h]	QDCV low [m3/h]	QDCV high [m3/h]	Qmin [m3/h]	QDCV [m3/h]
Total/AHU	**12613**	**32035**	**3333**	**12613**	**30230**	**12613**	**26193**	**30230**	**4204**	**10678**

The air volume is calculated with minimum requirements from TEK17 which gives a lower value of air supply per square meter then expected in a conventional project.

Result of the air volume calculation is used for design of the ventilation system, selection of Air Handling Unit, AHU, and for energy calculations.

3.3.2 REVIT model

REVIT is used for creating two different models, one model for case 1 and 2 with centralized system and one model for case 3 with decentralized system. The models in REVIT will be used for calculation of GWP with a REVIT plugin develop by Multiconsult.

The models are based on the floor plan for the 3rd floor. The 3rd floor consists of three different areas for office rental. All three areas consist of open landscape, meeting rooms, kitchen, and toilets. The floorplan for the 3rd floor is presented in Figure 5 in Chapter 3.1. For case 1 and 2 with centralized ventilation, AHU plant room is chosen to be located in floor 1 (basement), see red mark in Figure 7. Shaft to the left of the elevator is chosen as technical shaft for ventilation ducts, see red mark on Figure 7. For case 3 with decentralized ventilation system the room with red mark in Figure 8 is chosen for AHU plant room. The AHU in case 3 will have outdoor supply and exhaust on the façade. The room is chosen because it is facing north which reduces the temperature rise from the sun to the supply air. The room is also facing at the backyard which reduce the amount of emissions from the surrounding streets.

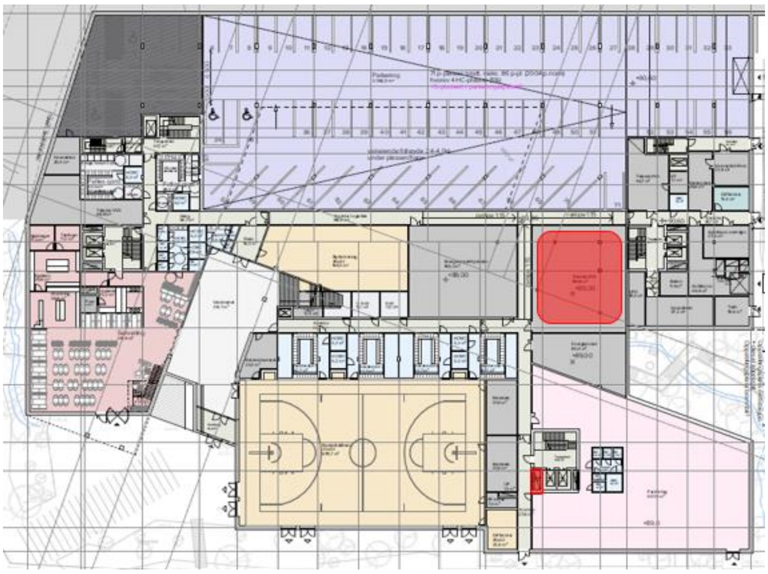

Figure 7. Draft of the 1st floor used in this thesis. Red mark shows area for AHU plant room and technical shaft for case 1 and 2. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

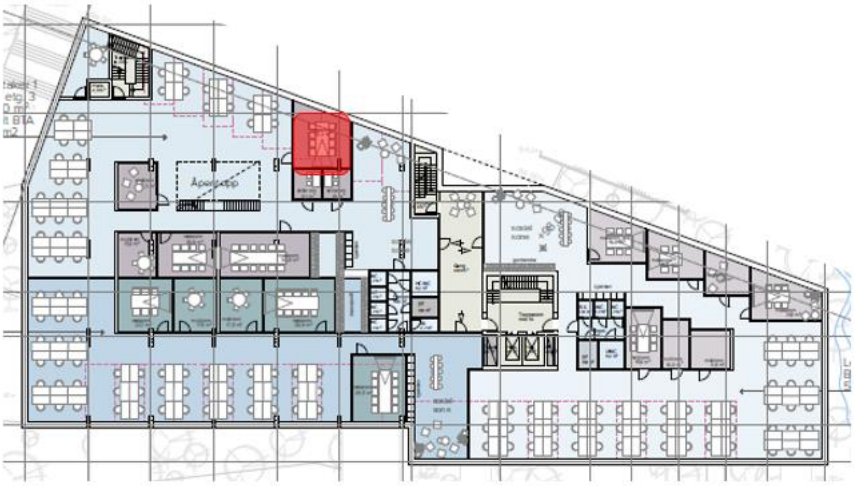

Figure 8. Draft of the 3rd floor used in this thesis. Red mark shows area for AHU plant room for case 3. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

For sizing of the main ducts, the design criteria of maximum air velocity, v= 7m/s is used [39].

For ducts with larger diameter than 1250 mm, rectangular ducts are used. For sizing of rectangular ducts an online software from Ventistål is used [40].
REVIT's sizing tool is used for sizing of other ducts with the design criteria of max 3-8 m/s shown in Figure 9. Ducts to air supply and exhaust units are sized with Q_{max}.

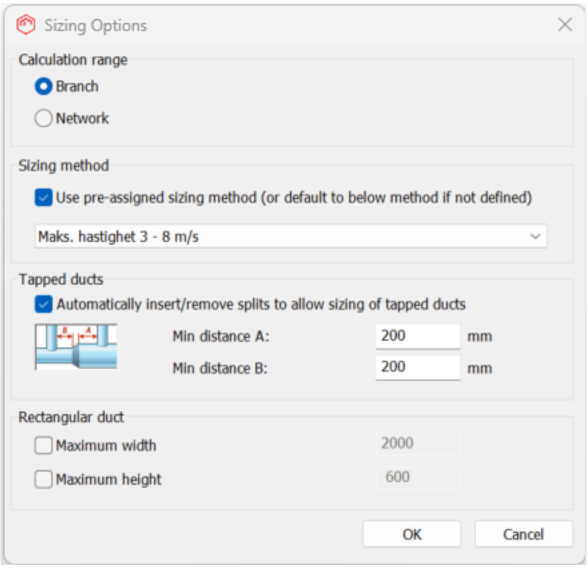

Figure 9. Set up for calculation of duct size in REVIT. Screenshot from REVIT.

Ducts for outdoor and exhaust air, AHU, Grills for outdoor and exhaust air, and Sound attenuators, LKK, around the AHU are not included in the model and manually estimated and added to the GWP calculation for each case. Estimation of ducts and grilles for outdoor and exhaust air is showed in Appendix C.

The REVIT model for case 1 and 2 is presented in Figure 10 and 11. The Figure 10 shows the ventilation system in the floor plan and Figure 11 shows a 3D model of the system with ducts in shaft to AHU plant room in floor 1.

Figure 10. The ventilation system for case 1 and 2. Screenshot from REVIT. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

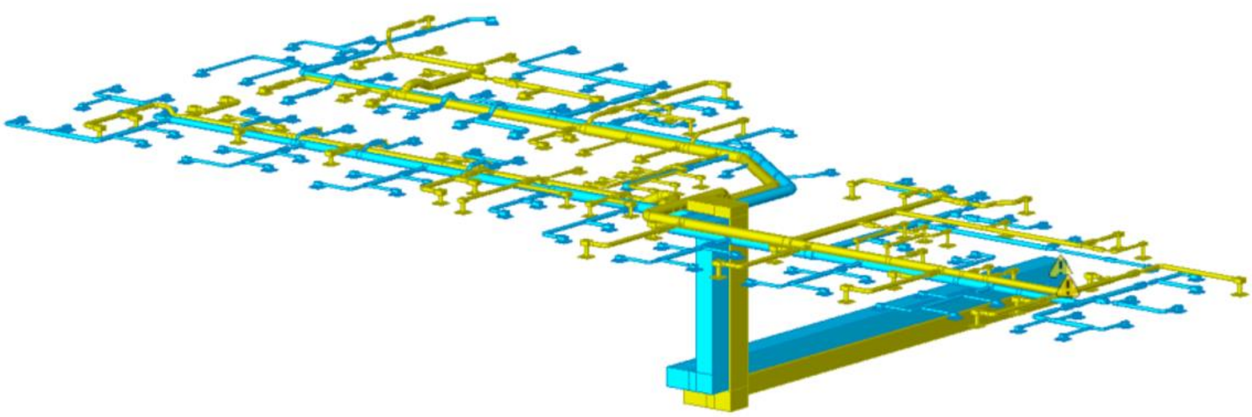

Figure 11. The ventilation system for case 1 and 2. Screenshot from REVIT. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

The REVIT model for case 3 is presented in Figure 12 and 13.

Figure 12. The ventilation system for case 3. Screenshot from REVIT. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

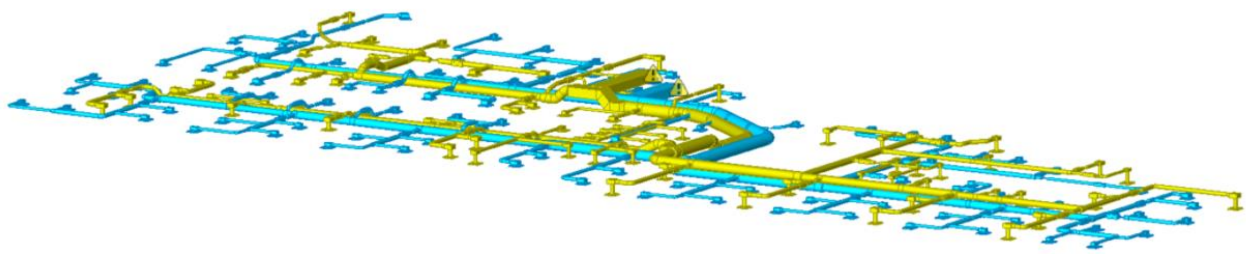

Figure 13. The ventilation system for case 3. Screenshot from REVIT. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan [33]. Figure with permission from Höegh Eiendom AS.

3.3.3 Air Handling Units, AHU

The choice of Air Handling Units, AHU, is of great importance for the total GWP. There is only two available AHU with EPDs in the market, eQ50 from FläktGroup AB/Ventistål AS and Gold RX 011/012 – Silver C RX 011/012 from Swegon AS. The Gold RX from Swegon is chosen as AHU for this thesis. Swegon have a product choice program, AHU design, which has been used for selecting of the AHU. AHU design from Swegon AS is an Eurovent Certified product selection tool [41].

Specific fan power, SFP, is a value of how efficient the air is distributed in the building. There are several types of SFP and SFPe is for energy calculations. SFPe is calculated with average air volume and external pressure drop over a year. [36]

TEK17 §14-2 regulates the energy framework of an office building to 115 kWh/m^2 heated BRA [42]. The energy framework is based on a calculation with a SFPe for the AHU to be ≤1.5 kW/(m^3/s) [35].

For all cases, several AHU dimensions and configurations can be suitable and to be able to choose one AHU for further calculations an election criterion has been developed:

The AHU with lowest GWP and with SFPe ≤ 1.5 kW/(m³/s) is chosen for further work.

Air volume Q_{DCV} calculator with Formula 1 in Chapter 3.3.1 and pressure drop estimated with Formula 4 and 5 from SN-NSPEK 3031:2012 *Energy performance of buildings, Calculation of energy needs and energy supply* Appendix F [43] is used in Swegons design tool, together with parameters in the list below:

- Unit type: Gold RX F.
- Energy recovery system: Rotary heat exchanger
- Flow combination: Supply-Extract Air.
- Control unit is included.
- Both Heating coil and Cooler coil with water is chosen.
- Other values are kept as default value from AHU design.

Estimation of pressure drop from SN-NSPEK 3031:2012 Appendix F [43]:

$$\Delta p_{ext,s} = \Delta p_{reg} + \left(\Delta p_{ext,dim} - \Delta p_{reg}\right) * r^2 \quad [Pa] \quad (4)$$

$$r = \frac{Q_{red}}{Q_{dim}} \quad [-] \quad (5)$$

r	*Part load factor for reduction of air volume in relation to dimensioning air volume*	-
$\Delta p_{ext,s}$	*Pressure drop over ductsystem with reduced air volume*	*Pa*
Δp_{reg}	*Lowest possible pressure drop over the ductsystem as results of VAV regulation. From table F.7 in SN-NSPEK 3031:2021*	*Pa*
$\Delta p_{ext,dim}$	*Pressure drop over ductsystem with dimensioning air volume. From table F.7 in SN-NSPEK 3031:2021*	*Pa*
Q_{red}	*Reduced air volume*	*m³/h*
Q_{dim}	*Dimensioning air volume*	*m³/h*

Results from estimation of pressure drop in duct system is presented in Table 10 and further described in Appendix D.

Table 10. Results from estimation of pressure drop in duct system.

		Case 01	Case 02		Case 03
	Unit		Low	High	
DeltaP ext,s	Pa	234	200	234	250

Three AHU is selected for each case for further evaluation and the results of the selection process are presented in Table 11-13 and Appendix E presents datasheet for the AHU's. AHU 1 for each case is the first dimension given from the design tool, AHU 2 is a larger AHU and AHU 3 is a smaller AHU from the design tool.

The first part of case 2, with lower occupancy factor, will use an AHU from Table 12 (Case 2) and the second part, with higher occupancy factor, will use an AHU from Table 11 (Case 1).

Table 11. Results from the selection of Air Handling Units for case 1 and second part of case 2. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44].

		Case 1		
		AHU 1.1	AHU 1.2	AHU 1.3
Model nr		100	80	120
Modifications		No	With droplet eliminator	With MPE (Maximum Pressure Efficiency) and filter ePM10 60% (M5)
SFPv	kW/(m3/s)	1,66	2,71	1,37
SFPe	kW/(m3/s)	1,78	2,94	1,49
Size	mm	4796x3340	4796x3440	4796x3340
Weight	kg	4357	2910	4477

Table 12. Result from the selection of Air Handling Units for the first part of case 2. For the second part of case 2 an AHU from case 1 is used. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44].

		Case 2		
		AHU 2.1	AHU 2.2	AHU 2.3
Model nr		100	80	120
Modifications		No	With droplet eliminator	No
SFPv	kW/(m3/s)	1,38	2,18	1,41
SFPe	kW/(m3/s)	1,5	2,38	1,57
Size	mm	4796x3340	4285x2637	4796x3340
Weight	kg	4310	2868	4510

Table 13. Result from the selection of Air Handling Units for case 3. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44].

		Case 3		
		AHU 3.1	AHU 3.2	AHU 3.3
Model nr		35	30	50
Modifications		No	With droplet eliminator	No
SFPv	kW/(m3/s)	1,77	2,95	1,37
SFPe	kW/(m3/s)	1,9	3,21	1,5
Size	mm	3560x1990	3328x1600	3815x2318
Weight pr AHU	kg	1461	1145	1796

Reference Service Lifetime, RSL, for the AHU is not specified in the EPD from Swegon AS. The report, *Levetider i praksis – Prinsipper og bruksområder*, by Multiconsult AS gives a functional life time for AHU of 16-20 years [45] and the EPD from Swegon AS gives an expected time of use of 20 years [24]. An Estimated Service Lifetime, ESL, for the AHU is chosen to be 20 years.

An AHU need to be placed in a technical room for ventilation, an AHU plant room. Byggforskserien Planløsning 379.310 – *Plassbehov og plassering av tekniske rom for ventilasjonsanlegg* gives guidance of minimum area of the AHU plant room calculated from the size of the AHU. Figure 14 and Formula 6-8 from Byggforskserien Planløsning 379.310 describes a calculation method. [46]

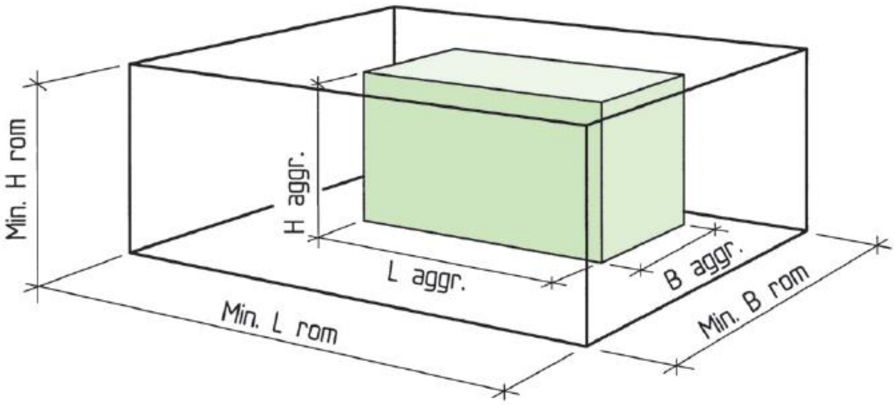

Figure 14. Area of plant room for ventilation can be calculated with the size of Air Handling Unit according to the figure from Byggforskserien Planløsning 379.310 - Plassbehov og plassering av tekniske rom for ventilasjonsanlegg [46].

$$Length_{room} = Length_{AHU} * 2{,}0 \quad [m] \quad (6)$$

$$Width_{room} = Width_{AHU} * 2{,}5 \quad [m] \quad (7)$$

$$Height_{room} = Height_{AHU} * 1{,}2 \quad [m] \quad (8)$$

Results of floor area calculation for AHU plant room with the method from Byggforskserien Planløsning 379.310 – *Plassbehov og plassering av tekniske rom for ventilasjonsanlegg* is showed in Table 14 and calculations is showed in Appendix F.

Table 14. Floor area for AHU plant room for ventilation system calculated with the method described in Byggforskserien Planløsning 379.310 – Plassbehov og plassering av tekniske rom for ventilasjonsanlegg.

		AHU 1.1	AHU 1.2	AHU 1.3	AHU 2.1	AHU 2.2	AHU 2.3	AHU 3.1	AHU 3.2	AHU 3.3
Size AHU	**[mm]**	4796x3340	4796x3440	4796x3340	4796x3340	4285x2637	4796x3340	3560x1990	3328x1600	3815x2318
Floor area	**[m2]**	80	82	80	80	56	80	35	27	44

3.4 Energy simulations

For calculation of B6, Energy in use, the delivered energy to the building needs to be calculated. IDA Indoor Climate and Energy 4.8 (IDA ICE 4.8) from EQUA is chosen as software for energy simulation. IDA ICE can perform a dynamic multi-zone simulation of thermal indoor climate and yearly energy consumption [47].

IDA ICE is chosen in front of other energy simulation tool because it has the opportunity to model one floor and then copy the floor to several floors. IDA ICE is also strong on calculation for demand control ventilation. A weakness with IDA ICE is the calculation with occupancy factor that will be simplified in large zones. For large and complex models IDA ICE is time consuming which also is a weakness.

IDA ICE simulates the indoor climate and energy consumption based on a model built in the program or imported to the program. For this master thesis a model is created in IDA ICE.

3.4.1 IDA ICE Model

A three-floor model is built in IDA ICE with one zone for each floor. The model is a simplification of the case building since the case building have a complex layout that is both time consuming and difficult to model and to simulate correctly. The model and zones are presented in Figure 15.

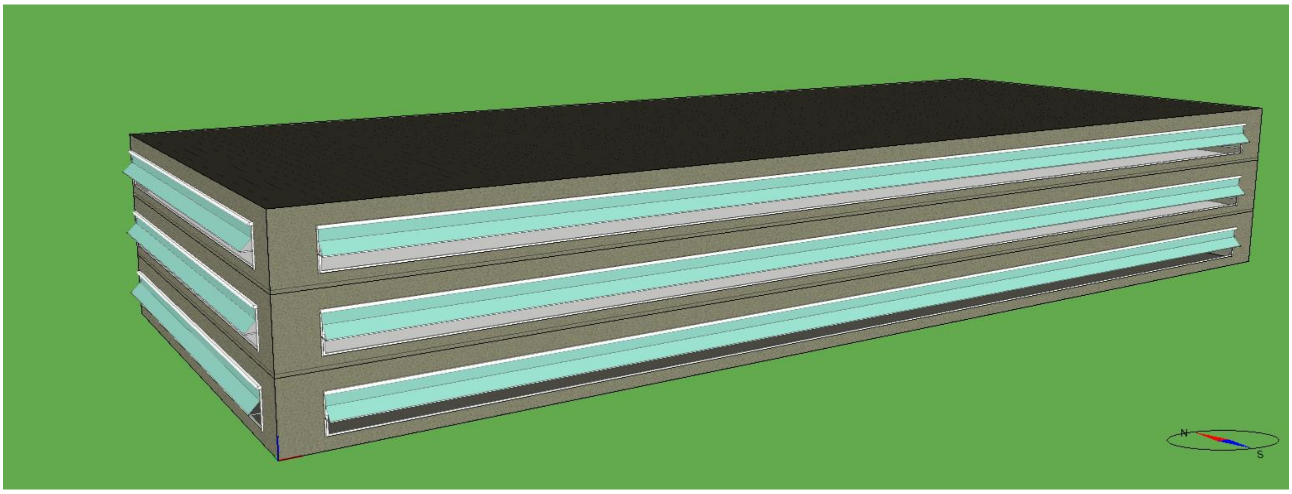

Figure 15. The model from IDA ICE used for energy simulation. The model is a simplification of the case building with one zone for each floor. Screenshot from IDA ICE.

At the time for the energy simulation, properties for the climate skin are not defined by the project group working with developing the case building, therefore assumed U-value from the group is used in the model. U-value used in energy simulation is showed in Table 15. The window area used in the model is modelled to be 17,5% of the floor area and to prevent overheating sun shading is included in the model.

Table 15. U-value used in energy simulation in IDA ICE [33].

Construction elements		
Roof	U-value [W/(m^2/K)]	0,11
Floor towards ground	U-value [W/(m^2/K)]	0,13
External wall	U-value [W/(m^2/K)]	0,16
Window	U-value [W/(m^2/K)]	0,75
Infiltration		0,4

Location and climate file is set to Oslo/Gardermoen. The case building is located in Oslo City however the climate file for Oslo/Gardermoen is used in simulation, due to availability of climate files. The wind profile is set to City center (ASHRAE 1993).

The intention for the case building regarding energy sources is to use borehole with heat pumps and district heating for peak load for heating and dry cooler for cooling peak load [33]. Due to the simplification made with the model and lack of information at the time for simulations the system boundary for the energy calculations is set to energy demand and the energy source is not considered. Therefore, the simulation is done with district heating as energy source.

The occupancy used in calculations in IDA ICE is found by calculating the numbers of chairs on the floorplan. The occupancy is 249 for each floor and 747 in total. The occupancy used in IDA ICE is the same as for calculations of air volume. The activity level is kept to the default level 1,0 MET and clothing is also kept as default to 0,85 ± 0,25 CLO. A schedule, presented in Figure 16, is modelled inspired by the PhD report, *Occupancy Patter in Office Buildings* by Halvarsson, curve for 24-hour profiles for occupancy in cellular office during working days with high occupancy [34].

In IDA ICE energy simulations, the program needs input on internal gains. The equipment is set to 8,6 W/m² and lighting is set to 3,7 W/m² according to SN-NSPEK 3031:2021 Addition A [43] and with the same schedule as for occupancy.

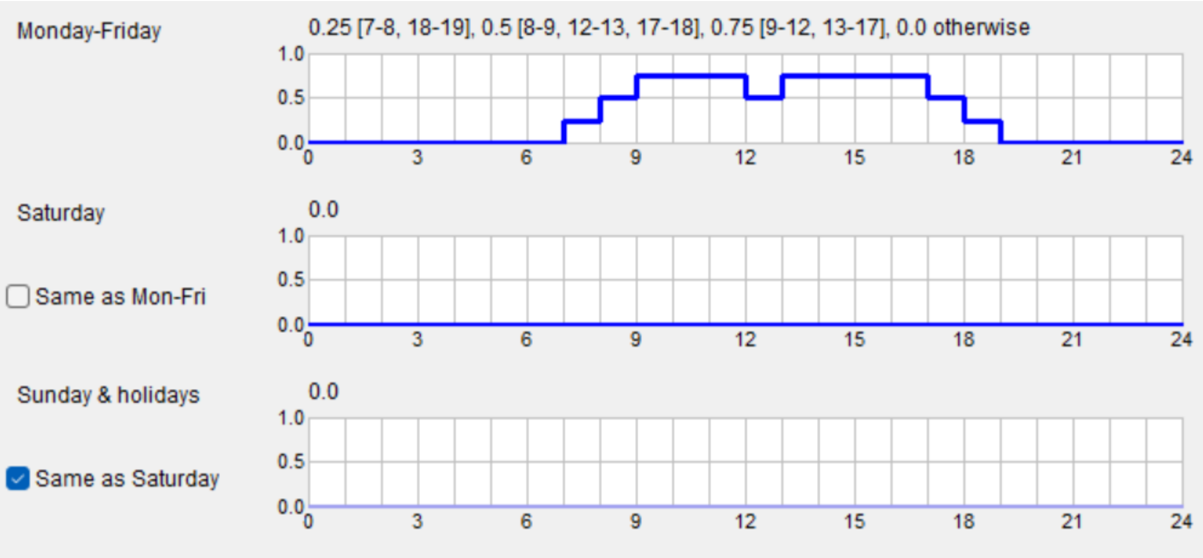

Figure 16. Schedule for occupancy and internal gains in IDA ICE inspired by PhD report, Occupancy Patter in Office Buildings by Halvarsson [34]. Screenshot from IDA ICE.

Local heating and cooling are used in all cases, and it is represented by adding an active beam as room units for each zone. The beam is modelled with the simplified model and dimensioned to cover the need for heating and cooling in the zone. The model is verified for sufficient capacity on heating and cooling with Heating load and Cooling load simulations.

Until this stage all three cases are having the same properties. Further on the model is copied in three copies as described in Table 16 and the air volume and AHU properties are set for each case.

Table 16. The three models used in energy simulations with number of AHU and their relation to the cases.

Model	Nr of AHU	Used in Case
1	1	• Case 1 • Case 2, second part with higher occupancy factor
2	1	• Case 2, first part with lower occupancy factor
3	3	• Case 3

The supply and return air volume are set according to the air volume for each case calculated in Chapter 3.3.1.

The Air Handling Unit is modelled with the default AHU model with VAV and temperature controlled in the HVAC Systems. The heat exchanger is changed to an enthalpy wheel air to air heat exchanger showed in Figure 17. The frost protection in the heat exchanger is set to -10°C according to SN-NSPEK 3031:2021 table F4 [43]. The setpoint temperature for supply air is kept constant at 19°C for all case. The SFP for the supply and return fan is changed according to SFPe for the selected AHU's for each case. One AHU connected to all zones is used in case 1 and 2 with centralized system. For case 3 with decentralized system one AHU for each zone is used, in total three AHU's.

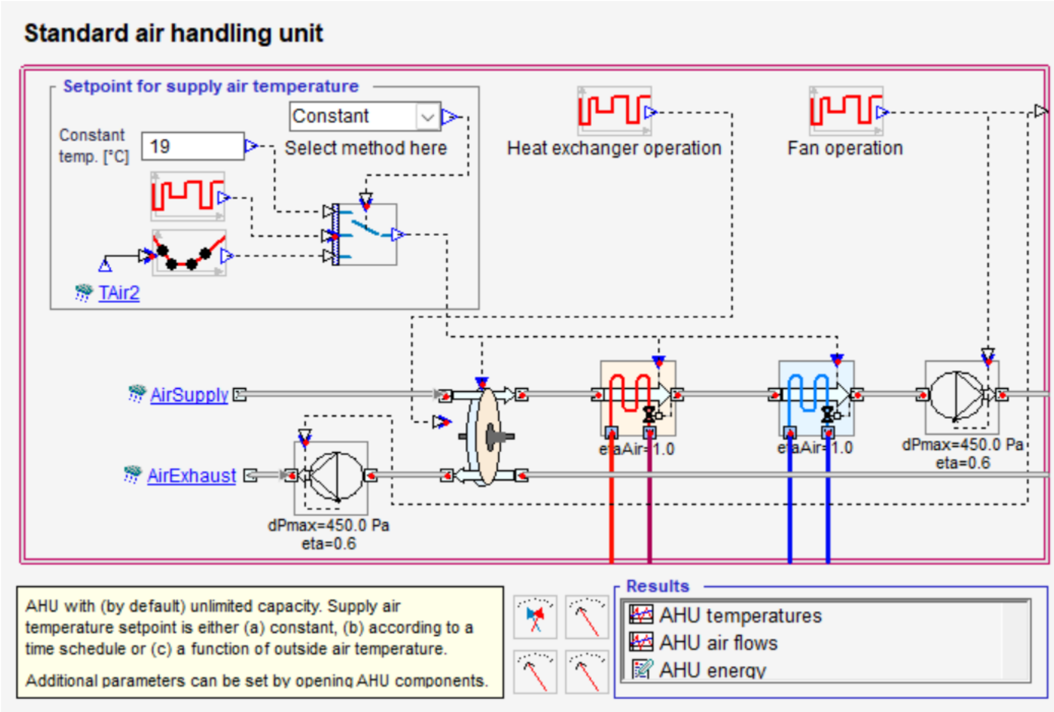

Figure 17. Air Handling Unit model in IDA ICE with enthalpy wheel air to air heat exchanger. Screenshot from IDA ICE.

3.4.2 Simulations for each case

Three models are built in IDA ICE according to the description above to find the yearly energy demand. For case 2 with two different set of AHU's, the first 20 years with lower occupancy factor is simulated with step 8 to 14. For the second part of case 2 with higher occupancy factor the simulation for step 1 to 7 is used. The simulations are performed as described below:

1. **Case 1 and Case 2 (second part) – IDA ICE Model nr 1**
   Set supply and return air to air volume for case 1.
2. Set SFP values to the SFPe values for AHU 1.1
3. Run simulation 1.1
4. Set SFP values to the SFPe values for AHU 1.2
5. Run simulation 1.2
6. Set SFP values to the SFPe values for AHU 1.3
7. Run simulation 1.3
8. **Case 2 (for the first 20 years with lower occupancy factor) – IDA ICE Model nr 2**
   Set supply and return air to air volume for case 2 (for the first 20 years with lower occupancy factor).
9. Set SFP values to the SFPe values for AHU 2.1
10. Run simulation 2.1
11. Set SFP values to the SFPe values for AHU 2.2
12. Run simulation 2.2
13. Set SFP values to the SFPe values for AHU 2.3
14. Run simulation 2.3
15. **Case 3 – IDA ICE Model nr 3**
    Set supply and return air to air volume for case 3.
16. Set SFP values for all three AHU to the values for AHU 3.1
17. Run simulation 3.1
18. Set SFP values for all three AHU to the values for AHU 3.2
19. Run simulation 3.2
20. Set SFP values for all three AHU to the values for AHU 3.3
21. Run simulation 3.3

The results of the simulations are summarised for each case in Table 17-19 and Appendix G shows the Delivered Energy report from IDA ICE. The model in IDA ICE cannot separate the amount of energy to each energy consumer, except for lighting and equipment. Therefore, the total amount of delivered energy includes all delivered energy except energy for lighting and equipment.

Table 17. Results of yearly delivered energy simulations for case 1 and second part of case 2. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. Energy from Delivered Energy Report in Appendix G.

		Case 1		
		AHU 1.1	AHU 1.2	AHU 1.3
Model nr		100	80	120
Modifications		No	With droplet eliminator	With MPE (Maximum Pressure Efficiency) and filter ePM10 60% (M5)
SFPv	kW/(m3/s)	1,66	2,71	1,37
SFPe	kW/(m3/s)	1,78	2,94	1,49
Size	mm	4796x3340	4796x3440	4796x3340
Weight	kg	4357	2910	4477
Energy -Scenario 1 NO	kW/year	384 796	406 115	379 462

Table 18. Result of yearly delivered energy simulations for the first part of case 2. For the second part of case 2 the energy simulations from case 1 is used. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. Energy from Delivered Energy Report in Appendix G.

		Case 2		
		AHU 2.1	AHU 2.2	AHU 2.3
Model nr		100	80	120
Modifications		No	With droplet eliminator	No
SFPv	kW/(m3/s)	1,38	2,18	1,41
SFPe	kW/(m3/s)	1,5	2,38	1,57
Size	mm	4796x3340	4285x2637	4796x3340
Weight	kg	4310	2868	4510
Energy -Scenario 1 NO	kW/year	377 970	394 795	379 310

Table 19. Result of yearly delivered energy simulations for case 3. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. Energy from Delivered Energy Report in Appendix G.

		Case 3		
		AHU 3.1	AHU 3.2	AHU 3.3
Model nr		35	30	50
Modifications		No	With droplet eliminator	No
SFPv	kW/(m3/s)	1,77	2,95	1,37
SFPe	kW/(m3/s)	1,9	3,21	1,5
Size	mm	3560x1990	3328x1600	3815x2318
Weight pr AHU	kg	1461	1145	1796
Energy -Scenario 1 NO	kW/year	387 899	411 559	380 672

3.5 LCA calculation

A LCA calculation is done according to the Norwegian Standard NS 3720:2018 *Method for greenhouse gas calculations for buildings*. The goal with the calculation is to compare the different cases and solutions for the ventilation system regarding Global Warming Potential, GWP.

The LCA calculations is based on the REVIT model, the chosen AHU and estimations of ducts and outer components described in Chapter 3.3 and energy from Chapter 3.4. The GWP for components modeled in REVIT is calculated by Multiconsult with their own developed REVIT plugin and database. The REVIT file was sent to Multiconsult and their calculations with the plugin resulted in an excel file with data on type, dimension, NS Code, units, GWP/unit, GPW total for A1-A3, number of installations based on lifetime and other information. GWP data for AHU, energy, ducts, and other components that is not included in the REVIT file is added manually to the LCA calculation. The method for calculations is further described in Chapter 3.5.2.

The LCA calculation is done for building components in system 362 Duct network for air treatment, 364 Equipment for air distribution and 365 Equipment for air treatment according to NS 3451:2022 as described in Table 4 in Chapter 2.4. All electronics and control systems in the ventilation system are excluded from the calculation.

The lifetime of the building is set to 60 years. The lifetime of the included components is from Multiconsult's database [48], EPDs [24] [49] or the report *Levetider i praksis – Prinsipper og bruksområder*, by Multiconsult AS [45]. Appendix H lists all components and lifetimes used in calculations.

System boundary for the calculation describes which modules that are included in the calculation and the system boundary is set to include:

- A1-A3, Production
- B4, Replacement
- B6, Operational energy use

All information modules, A1-A5, B1-B5 and C1-C4 and where applicable D, should be included when performing a LCA calculation of material, product and building materials according to 7.4 in NS 3720:2018 [10]. Due to lack of data on stage A4-A5, B1-B5, C1-C4 and D in Multiconsults database and due to limitation of time it is chose to only include A1-A3, B4 and B6. Rabani et al. also shows in their study of an office building that C1-C4 for ventilation system is marginal [18]. B4 is of great interest for calculation on HVAC system due to the short lifetime of several components and B6 is of interest when comparing the cases. The system boundary for energy calculations is set to the amount of deliver energy to the building and not considering the source of energy.

GWP data that is used in this LCA is presented in Table 20. The first choice is data included in Multiconsults database. The database does not include all data needed in this LCA therefore GWP data needs to be included manually. Source of manually added GWP data is also listed in table 20 and the method for manually included data is described in Chapter 3.5.3.

Table 20. Source of GWP data included in this LCA.

	Producer	EPDnr	Source:
Multiconsult database			[48]
Energy emission factor			[10]
Manually added data for components not included in Multiconsult database			
Gold RX 011/012 – Silver RX 011/012	Swegon Group AB	S-P-05063	[24]
eQ50	FläktGroup AB / Ventistål AS	NEPD-3290-1935-NO	[25]
LKK 1600-1000-1500-3165C	Trox Auranor Norge AS	NEPD-4047-3075-NO	[49]
VAV LEO - 160	Trox Auranor Norge AS	NEPD-4048-3076-EN	[50]

3.5.1 Quality of LCA data

NS 3720:2018 defines two levels of data quality. Level 1 is for data that is specified for a specific product or service in a certain time. To fulfill level 1 the data must be from a EPD that is third party verified according to NS-EN 15804. Level 2 is for all other LCA data that do not fulfill the requirement in level 1. Example on level 2 data is generic data, average data, or industry data. [10]

In this LCA study, both data from EPD that fulfill level 1 and generic data from level 2 is included. The first choice is data from Multiconsults database which includes both level 1 and level 2 data, however for AHU only data from the EPD is used. For products that are not included in the Multiconsults database, a strategy for selecting data is described in Chapter 3.5.3 and manually added EPDs for products not included in Multiconsults database used are presented in Table 20.

3.5.2 Calculation of GWP

Excel is used for calculations of the GWP for this master thesis. The REVIT plugin gives the result in an Excel file which makes it easy to process further in Excel together with manually added data.

An Excel spreadsheet that collects, calculate and summaries the result in charts is developed. The spreadsheet calculates the cases in separate sheet and a summary sheet compares the cases. Figure 18 shows an illustration of the spreadsheet for calculation of the cases. The method for the calculations is divided into five steps.

1. Collect and fill in data in the green area. The chosen AHU is filled in with weight and GWP data. Delivered energy from the energy calculation in IDA ICE is filled in together with GWP data for Scenario 1 and Scenario 2. The result from the REVIT plugin is copied and data is manually added for components without GWP data in the plugin result file, see more about manually added components in Chapter 3.5.3.

2. Fill in system codes according to NS 3451:2022 in the yellow area. Number of re-installations, based on the service lifetime of the building and the estimated service lifetime of the components, is also filled into the yellow area. The yellow area also contains a factor that multiply the data in the green area, for example the result from the REVIT plugin is multiplied with three to compensate that is only one floor that is calculated in the plugin, but the LCA is made for three floors. The energy is multiplied with one because the IDA ICE calculation is made with a three-floor model for the whole building.

3. Calculate the GWP for each component and module with Formula 9 to 14 described in this chapter.

4. Summarize the results of the calculations in the red areas with tables for each energy scenario and to draw charts.

5. All the three cases are combined and compared in the summary sheet.

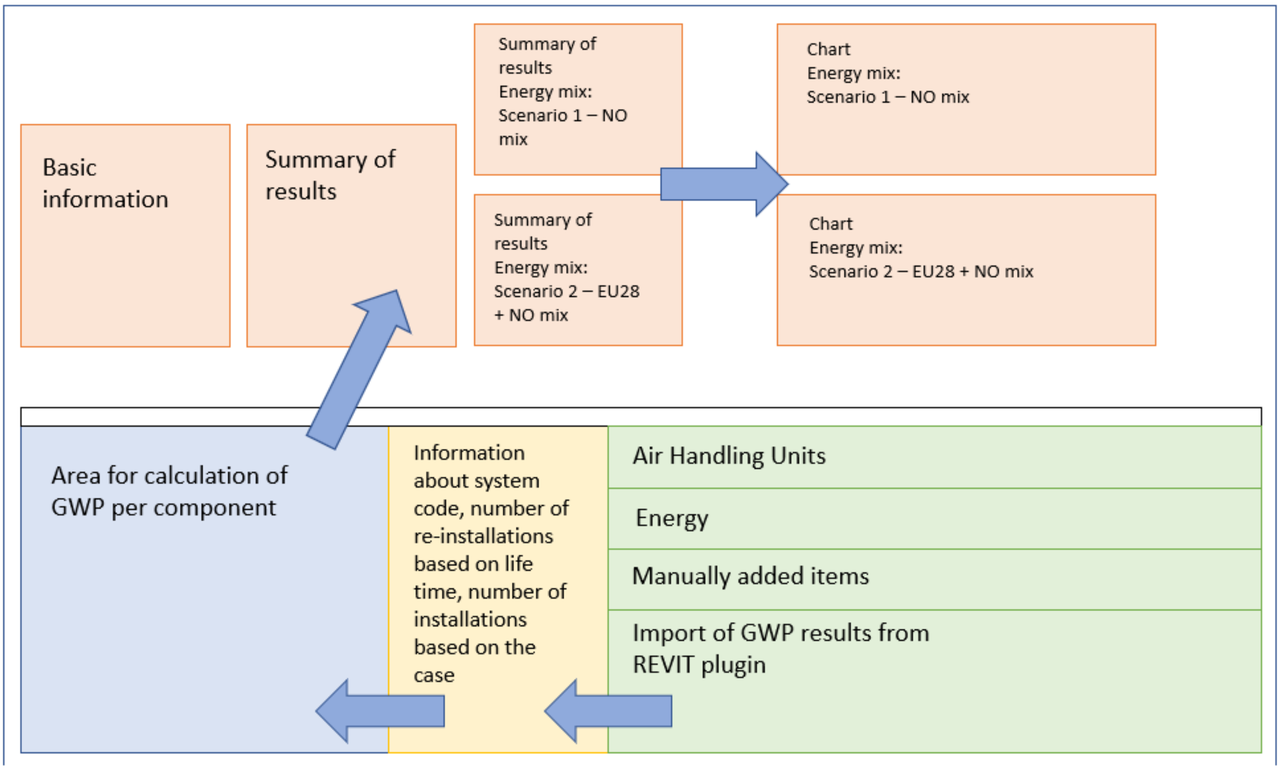

Figure 18. Illustration of the spreadsheet and method for calculation of GWP.

The calculation of the GWP for each module is done with Formula 9 from NS-EN15978:2011 *Sustainability of construction works Assessment of environmental performance of buildings Calculation method* [51].

$$GWP_i = \sum_{n=1}^{N} a_{n,i} * GWP_{an,i} \quad [kg\ CO_2 - eq] \qquad (9)$$

GWP_i	*Global warming potential for module i*	*kg CO_2-eq*
$a_{n,i}$	*Number of product or service n used in module i*	-
$GWP_{an,i}$	*Global warming potential for one product or service n used in module i*	*kg CO_2-eq/unit*

For calculations of B4, Replacement, NS 3720:2018 specifies that Formula 10 from NS-EN15978:2011 shall be used to find the number of replacements from the estimated service lifetime of the product and the Required Service Life for the building [10] [51]. The function E, that rises the result of the inner part of the equation to nearest integer is not used in this calculation. When performing a full building LCA the function E shall be used. In this case when the goal is to compare different solutions the function is not used since we are not considering what's happening after 60 years. Formula 11 described in NS-EN 15804:2012+A2+AC *Sustainability of construction works Environmental product declarations Core rules for the product category of construction products* is then used to find the GWP for module B4 [52].

$$N_R(n) = E\left[\frac{ReqSL}{ESL(n)} - 1\right] \quad [-] \quad (10)$$

$$GWP_{B4} = \sum_{n=1}^{N} a_n * GWP_{an,(A1-A5)+(C1-C4)} * N_R(n) \quad [kg\ CO_2 - eq] \quad (11)$$

$N_R(n)$	*Number of replacements of product n*	-
E	*Function that rises to nearest integer*	-
ReqSL	*Required Service Life*	*year*
ESL(n)	*Estimated lifetime of product n*	*year*
GWP_{B4}	*Global warming potential for module B4*	*kg* CO_2*-eq*
a_n	*Number of product or service n used*	-
$GWP_{an,(A1-A5)+(C1-C4)}$	*Global warming potential for one product or service n used in module A1-A5 and C1-C4*	*kg* CO_2*-eq/unit*

The total GWP for all included modules is found by adding all modules to a total GWP for each case with Formula 12.

$$GWP_{Total} = GWP_{A1-A3} + GWP_{B4} + GWP_{B6} \quad [kg\ CO_2 - eq] \quad (12)$$

GWP_{Total}	*Total Global warming potential*	*kg* CO_2*-eq*
GWP_{A1-A3}	*Global warming potential for Product module A1-A3*	*kg* CO_2*-eq*
GWP_{B4}	*Global warming potential for Replacement*	*kg* CO_2*-eq*
GWP_{B6}	*Global warming potential for Operational energy use*	*kg* CO_2*-eq*

3.5.3 Components without GWP data in the database

Not all components have GWP data in the result file from the REVIT-plugin. A method for finding GWP data and to manually add the data to the results for those components is developed. Example of products that are modeled in REVIT but not have a result in the plugin file are air flow controller and tees with sizes not included in the database.

AHU and ducts for outdoor/exhaust air are not included in the REVIT model and therefore not in the result file. GWP for AHU is calculated in Chapter 3.5.5 and manually added to the result. Ducts for outdoor/exhaust air are estimated for each case and added to the result.

The method and prioritized sequence for finding GWP data for manually added products/components are:

1. Use product specific EPD for the component.
2. Use product specific GWP data from Multiconsult database. (For components that are in the database but not in the REVIT file)
3. Calculate GWP with data from EPD for the same product but with different size and with dimension/weight from supplier.
4. Calculate GWP with data from Multiconsult database for the same product but with different size and with dimension/weight from supplier.

Table 21 shows products that are manually calculated and method used for calculation. Calculation of the AHU is showed in Chapter 3.5.5. Formula 13 is used for calculation of the GWP in method 3 and 4.

$$GWP_{Product\ without\ GWP} = \frac{GWP_{Product\ with\ GWP}}{M_{Product\ with\ GWP}} * M_{Product\ without\ GWP} \quad [kg\ CO_2 - eq] \quad (13)$$

$GWP_{Product\ without\ GWP}$	*Global warming potential for product without GWP data*	*kg CO_2-eq*
$GWP_{Product\ with\ GWP}$	*Global warming potential for product with GWP data*	*kg CO_2-eq*
$M_{product\ with\ GWP}$	*Weight of product with GWP data*	*kg*
$M_{product\ without\ GWP}$	*Weight of product without GWP data*	*kg*

Table 21. Product without GWP data in Mulitconsult database that are manually calculated including method for calculation and source.

Product without GWP data in Multiconsult database	Calculation method	Source:
Orion-LOV-TA-X+Luna-X	4	[48] [53]
Leo-0-X	3	[50] [54]
Orion-ATV-S-T-X+Luna-X	4	[48] [55]
TCPU - Tee	4	[48] [56]
TCU - Tee	4	[48] [57]
AHU	3	[24] [44]
Duct – Outdoor/Exhaust air	2	[48]
Grilles	4	[48] [58]
LBR – Duct Fittings etc.[1.]	4	[48] [59]
LKK – Sound attenuators	3	[49] [60] [61]

[1.] The weight for LBR and duct fittings are calculated with a formula provided by the supplier.

NS3720:2018 defines that product in small amount, up to five weight percent of a two number building code level, can be left out of the calculation if GWP data is not available [10]. Five items in building code 362 are left out of this calculation:

- Case 1: 2 items of magirect_outlet1_001-1300x500 Tap – Adjustable
- Case 2: 2 items of magirect_outlet1_001-1300x500 Tap – Adjustable
- Case 3: 1 item of magirect_outlet1_001-900x500 Tap – Adjustable

3.5.4 Energy in use

NS 3720:20128 defines that energy in use module B6, Operational energy use, shall be calculated with NS 3031:2014, SN/TS 3031:2016 or based on measurements of consumed electricity for buildings in use. The calculation shall be based on calculation point C, delivered energy described in NS 3720:2018 figure 3 [10]. IDA ICE is used for calculation of delivered energy in this LCA. The method for energy calculation is described in Chapter 3.4. B6, Operational energy use, in this LCA includes all energy delivered to the building from the Delivered Energy report in IDA ICE, but energy for lighting and equipment is excluded.

Formula 14 form NS 3720:2018 is used for calculation of GWP from delivered energy during the lifetime. [10]

$$GWP_{B6} = \sum_{i=1}^{N} \sum_{t=1}^{T} e_{deliverd}(i,t) * f_{deliverd}(i,t) \quad [kg\ CO_2 - eq] \quad (14)$$

GWP_{B6}	*Total emission from energy in use during lifetime*	*kg CO_2-eq*
i	*Energy consumer unit*	-
T	*Maximum timestep*	*year*
t	*Timestep*	*year*
$e_{deliverd}$	*Delivered energi for energy consumer unit in timestep,t*	*kWh*
$f_{deliverd}$	*CO_2 emission factor for enery consumer unit, i*	*kg CO_2-eq/kWh*

The time, T, for the calculation is set to 60 years and the timestep, t, is set to 1 year.

GWP from B6, Operational energy use, is calculated for two different scenarios. Scenario 1 for Norwegian energy mix and Scenario 2 for European energy mix. The CO_2 emission factor are taking into account the production and the source of the energy. Scenario 1 based on Norwegian energy production have a factor of 0,0180 kg CO_2-eq/kWh and Scenario 2 based on Eurostat and EU Roadmap 2050 have a factor of 0,136 kg CO_2-eq/kWh [10].

When the object is located inside the concession area for district heating and cooling, and district heating and cooling is to be used, product specific data for district heating and cooling shall be used [10]. Since Bøkkerveien 1-3 is located inside the concession area for Oslo district heating [62], CO_2-eq emissions from district heating shall be used for calculation of emission from heating. However due to simplifications done with the model for energy simulation in IDA ICE, the energy simulation cannot distinguish between the source of energy. Therefore, GWP for B6 is only calculated with Scenario 1 NO mix and Scenario 2 EU28+NO mix for all energy. See Table 22 for a presentation of CO_2-eq used in calculation of GWP for B6 for the two different scenarios and for district heating and cooling for comparison.

Table 22. GWP data for calculation of B6, energy in use.

	Unit	**GWP**	**Source:**
Scenario 1 - NO	kg CO_2-eq/kWh	1,80E-02	[10]
Scenario 2 - EU28+NO	kg CO_2-eq/kWh	1,36E-01	[10]
District heating	kg CO_2-eq/kWh	2,00E-02	[63]
District cooling	kg CO_2-eq/kWh	1,85E-02	[64]

3.5.5 Calculation of GWP for AHU

Three AHU is selected for each case in Chapter 3.3.3 to be further evaluated regarding the GWP for one life cycle of the AHU and with the SFP criteria. The best AHU for each case will then be used in calculations for the cases. This section describes the method for evaluation and calculation of GWP.

After selection of AHU in Chapter 3.3.3 the GWP for the AHU is calculated with GWP data from the EPD, S-P-05063 Gold RX 011/012 – Silver C RX 011/012. The EPD only gives data for one dimension of the AHU, therefore the GWP data in the EPD is divided by the mass of the AHU in the EPD to give a GWP/kg, see Table 23. The GWP/kg factor is then multiplied with the weight of the chosen AHU. It is chosen to use weight (kg) as scaling factor. Other possible scaling factors could have been air volume (m^3/h).

Table 23. Global Warming Potential for AHU Gold RX 011/012 – Silver C RX 011/012 and GWP/kg [24].

	Unit	A1-A3	A4	A5	C1	C2	C3	C4	Total excl. D	D
Gold RX 12 - GWP	kg CO2-eq	2,46E+03	1,65E+01	6,60E+01	1,66E-01	4,38E+00	3,75E+01	6,00E+00	2,59E+03	-8,39E+02
GWP/kg	kg CO2-eq/kg	5,04E+00	3,38E-02	1,35E-01	3,40E-04	8,98E-03	7,68E-02	1,23E-02	5,31E+00	-1,72E+00

The EPD for Gold RX 011/012 – Silver C RX 011/012 specifies that it can only be used for Gold RX 011/012, Silver C RX 011/012, as well as products with similar configuration and weight [24], however in absence of EPD for larger AHU the EPD is used for all dimensions.

It is chosen to compare the AHU with the perspective of one life cycle for the AHU's and with the GWP for energy calculated with the Norwegian mix in Scenario 1 from Table 22. The Estimated Service Lifetime is set to 20 years in Chapter 3.3.3 and therefore the energy in use (kW/year) presented in Table 17-19 is multiplied with 20 to get the energy for one life cycle. The total emission from energy in use during one life cycle is calculated with Formula 14 in Chapter 3.5.4.

All modules declared in the EPD is used in the comparison of the GWP for AHU's, however only A1-A3 is used in the calculation for the cases.

The result of the Global Warming Potential calculation for the AHU is presented in Table 24-26 and further discussed in the result Chapter 4.3.

Table 24. Total Global Warming Potential for AHU for case 1 and the second part of case 2. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. GWP for A1-A5 and C1-C4 is calculated with EPD S-P-05063 Gold RX 011/012 – Silver C RX 011/012 [24]. Energy from Delivered Energy Report in Appendix G. GWP for B6 is calculated with Energy – Scenario 1 – NO mix [10].

		Case 1		
		AHU 1.1	**AHU 1.2**	**AHU 1.3**
Model nr		100	80	120
Modifications		No	With droplet eliminator	With MPE (Maximum Pressure Efficiency) and filter ePM10 60% (M5)
SFPv	**kW/(m3/s)**	1,66	2,71	1,37
SFPe	**kW/(m3/s)**	1,78	2,94	1,49
Size	**mm**	4796x3340	4796x3440	4796x3340
Weight	**kg**	4357	2910	4477
GWP AHU A1-A5 and C1-C4	**kg CO2-eq**	2,31E+04	1,54E+04	2,38E+04
Energy -Scenario 1 NO	**kW/year**	384 796	406 115	379 462
GWP Energy B6 - Scenario 1 NO (20 year)	**kg CO2-eq**	1,39E+05	1,46E+05	1,37E+05
Total GWP	**kg CO2-eq**	**1,62E+05**	**1,62E+05**	**1,60E+05**

Table 25. Total Global Warming Potential for AHU for the first part of case 2. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. Energy from Delivered Energy Report in

Appendix G. GWP for A1-A5 and C1-C4 is calculated with EPD S-P-05063 Gold RX 011/012 – Silver C RX 011/012 [24]. GWP for B6 is calculated with Energy – Scenario 1 – NO mix [10].

		Case 2		
		AHU 2.1	AHU 2.2	AHU 2.3
Model nr		100	80	120
Modifications		No	With droplet eliminator	No
SFPv	**kW/(m3/s)**	1,38	2,18	1,41
SFPe	**kW/(m3/s)**	1,5	2,38	1,57
Size	**mm**	4796x3340	4285x2637	4796x3340
Weight	**kg**	4310	2868	4510
GWP AHU A1-A5 and C1-C4	**kg CO2-eq**	2,29E+04	1,52E+04	2,39E+04
Energy -Scenario 1 NO	**kW/year**	377 970	394 795	379 310
GWP Energy B6 - Scenario 1 NO (20 year)	**kg CO2-eq**	1,36E+05	1,42E+05	1,37E+05
Total GWP	**kg CO2-eq**	**1,59E+05**	**1,57E+05**	**1,60E+05**

Table 26. Total Global Warming Potential for AHU for case 3. Information of the AHU from datasheet in Appendix E and from AHU Design software by Swegon AS [44]. GWP for A1-A5 and C1-C4 is calculated with EPD S-P-05063 Gold RX 011/012 – Silver C RX 011/012 [24]. Energy from Delivered Energy Report in Appendix G. GWP for B6 is calculated with Energy – Scenario 1 – NO mix [10].

		Case 3		
		AHU 3.1	AHU 3.2	AHU 3.3
Model nr		35	30	50
Modifications		No	With droplet eliminator	No
SFPv	**kW/(m3/s)**	1,77	2,95	1,37
SFPe	**kW/(m3/s)**	1,9	3,21	1,5
Size	**mm**	3560x1990	3328x1600	3815x2318
Weight pr AHU	**kg**	1461	1145	1796
GWP AHU A1-A5 and C1-C4	**kg CO2-eq**	2,33E+04	1,82E+04	2,86E+04
Energy -Scenario 1 NO	**kW/year**	387 899	411 559	380 672
GWP Energy B6 - Scenario 1 NO (20 year)	**kg CO2-eq**	1,40E+05	1,48E+05	1,37E+05
Total GWP	**kg CO2-eq**	**1,63E+05**	**1,66E+05**	**1,66E+05**

The AHU with lowest total GWP over one life cycle and that fulfil the criteria of SFPe ≤ 1,5 kW/(m^3/s) is used in the LCA calculations for each case, see Table 27.

3.5.6 LCA calculations for cases

The calculations of GWP for each case contains of data from several parts, for example REVIT plugin results and energy calculations, earlier described inn this thesis. Table 27 present which data that is included in each case.

The result from the GWP calculation is presented and discussed in Chapter 4.

Table 27. Included data in the GWP calculations for each case.

	Case 1	**Case 2**	**Case 3**
REVIT plugin file Result from REVIT plugin file that is included in the GWP calculation and factor for multiplication	3 x REVIT plugin case 1 and 2	3 x REVIT plugin case 1 and 2	3 x REVIT plugin case 3
Main duct	Included with the REVIT plugin but manually set to only be included one time.	Included with the REVIT plugin but manually set to only be included one time	Included 3 times with REVIT plugin.
Energy calculations Energy calculations done with the result from IDA ICE model	60 years x IDA ICE Model 1.3	20 years x IDA ICE Model 2.1 40 years x IDA ICE Model 1.3	60 years x IDA ICE Model 3.3
AHU	1 installation and 2 replacements with AHU 1.3	1 installation with AHU 2.1 and 2 replacements with AHU 1.3	1 installation and 2 replacements with 3 units of AHU 3.3

4 Results and discussion

Chapter 4 will present the results from the LCA calculation described in Chapter 3. The result will first be presented and discussed for all three cases in general. In Chapter 4.2 the cases will be compared to each other and final in Chapter 4.3 the result from the Air Handling Unit study will be presented and discussed.

4.1 Result of the Life Cycle Assessment

The result from the Life Cycle Assessment calculations for Global Warming Potential for the ventilation system developed and method described in this thesis are presented in Table 28, Figure 19, and Figure 20. Figure 19 presents the results for module A1-A3, Product, B4, Replacement and B6, Operational Energy use calculated with Scenario 1 – NO mix. Figure 20 shows the result for the same modules and with Scenario 2 – EU28+NO mix for calculation of B6.

The LCA study is limited to include the environmental impacts on Climate change/Global Warming Potential and the analyse time used in the calculation is set to 60 years.

The result of the calculations shows that the difference in Global Warming Potential between the three cases is small. When looking at Scenario 1 – NO mix, case 3 with decentralized system has the lowest GWP with 120,75 kg CO_2-eq/m^2 followed by case 2 with 122,53 kg CO_2-eq/m^2 and case 1 with 122,81 kg CO_2-eq/m^2. When looking at Scenario 2 – EU28+NO mix, case 2 has the lowest GWP with 664,63 kg CO_2-eq/m^2 followed by case 3 with 665,30 kg CO_2-eq/m^2 and case 1 with 665,62 kg CO_2-eq/m^2.

The amount of energy used in the calculations for Scenario 1 and Scenario 2 is the same, but the CO_2 emission factor is different. The CO_2 emission factor is taking into account the production and the source of the energy. Scenario 1 based on Norwegian energy production have a factor of 0,0180 kg CO_2-eq/kWh and Scenario 2 based on Eurostat and EU Roadmap 2050 have a factor of 0,136 kg CO_2-eq/kWh [10]. It is the difference in CO_2 emission factor that changes the order between the cases in the results for Scenario 1 and Scenario 2. Further on in this chapter the analysis will be done with the Norwegian mix in Scenario 1.

B6, Operational energy use, is the largest contributor to the total GWP for all cases. However, it is the difference in B6 that is interesting when comparing the cases. The amount of energy used in calculation of B6 is from the energy simulation in IDA ICE and includes all delivered energy to the building, excluded energy for lighting and equipment. It is not possible to separate energy used in the ventilation system from the energy used for heating and cooling in the result from IDA ICE, therefore the amount of energy is high compared to the other modules. When comparing the difference in B6 there are only small differences in the GWP for the chosen configuration of Air Handling Units and air volumes. The result of the IDA ICE energy simulation and calculation of GWP for Air Handling Unts will be discussed more in detail below.

B4, Replacement, is higher than A1-A3, Product, for all cases due to short lifetime on several of the components in a ventilation system. An example of a component with shorter lifetime than the analyse period is Air Handling Units. The AHU have an Estimated Service Lifetime of 20 years which makes it necessary to replace and re-install the AHU two times during a 60 year period. Therefore, module A1-A3, Product, will include CO_2-emissons for one AHU and module B4, Replacement, will include CO_2-emissons for two AHU, in total CO_2-emissons for three AHU. The largest difference between the cases when comparing modules is in module A1-A3, Product.

Table 28. Results from the calculation of Global Warming Potential in kg CO_2-eq/m² BTA for A1-A3, Product, B4, Replacement and B6, Operational energy use, for the three cases. B6, Operational energy use, with Scenario 1 – NO mix and with Scenario 2 – EU28+NO mix.

Global Warming Potential for A1-A3, B4 and B6 kg CO_2-eq/m² BTA				
	Unit	**Case 1**	**Case 2**	**Case 3**
A1-A3 Product	kg CO_2-eq/m²	17,20	17,03	15,59
B4 Replacement	kg CO_2-eq/m²	22,80	22,80	22,10
B6 Operational Energy use – Scenario 1 – NO mix	kg CO_2-eq/m²	82,80	82,69	83,07
B6 Operational Energy use – Scenario 2 – EU28+NO mix	kg CO_2-eq/m²	625,61	624,79	627,61
GWP Total - Scenario 1 – NO mix	**kg CO_2-eq/m²**	**122,81**	**122,53**	**120,75**
GWP Total - Scenario 2 – EU28 + NO mix	**kg CO_2-eq/m²**	**665,62**	**664,63**	**665,30**

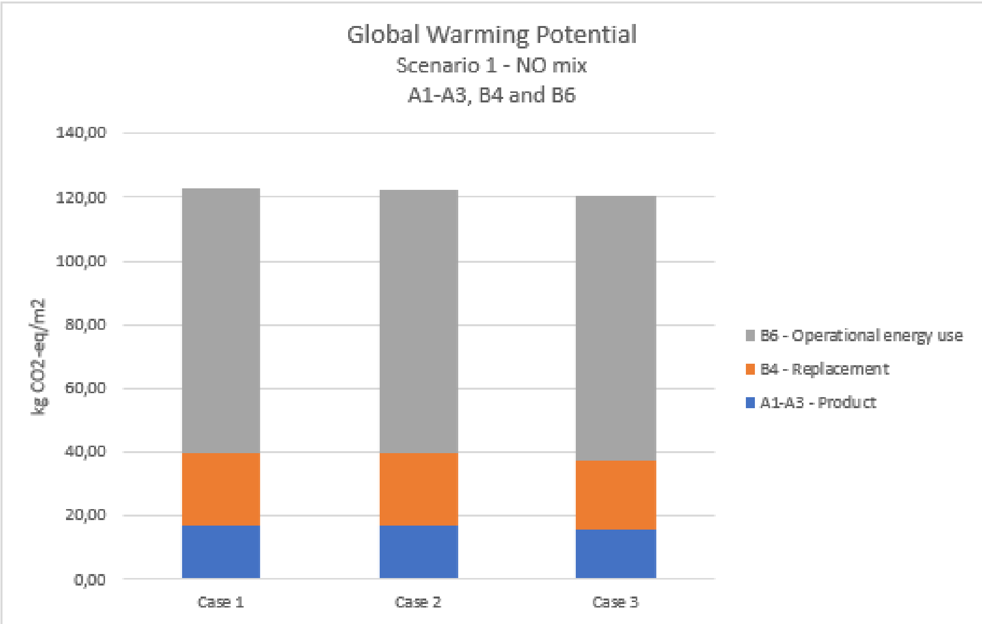

Figure 19. Results from the calculation of Global Warming Potential in kg CO_2-eq/m² BTA for A1-A3, Product, B4, Replacement and B6, Operational energy use, for the three cases. B6, Operational energy use, with Scenario 1 – NO mix.

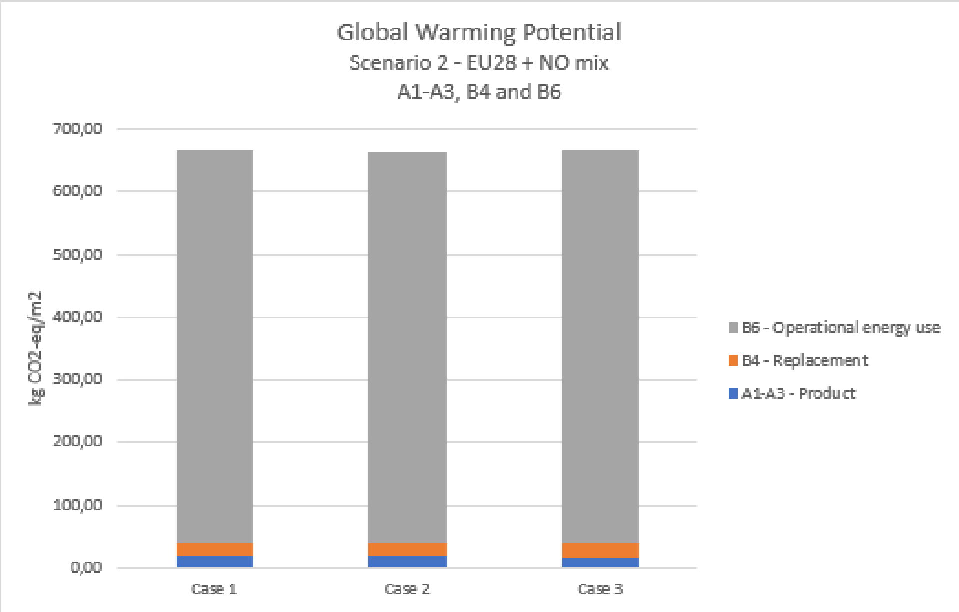

Figure 20. Results from the calculation of Global Warming Potential in kg CO_2-eq/m^2 BTA for A1-A3, Product, B4, Replacement and B6, Operational energy use, for the three cases. B6, Operational energy use with Scenario 2 – EU28+NO mix.

4.2 Case comparison

When comparing the cases, it is interesting to look at the GWP divided into building element categories to find the difference between the cases. All components in the GWP calculation are marked with building elements category according to NS 3451:2022. Figure 21 and Figure 22 presents the GWP for the three cases dived in building elements. Figure 21 includes B6, Operational energy use, for Scenario 1 – NO mix.

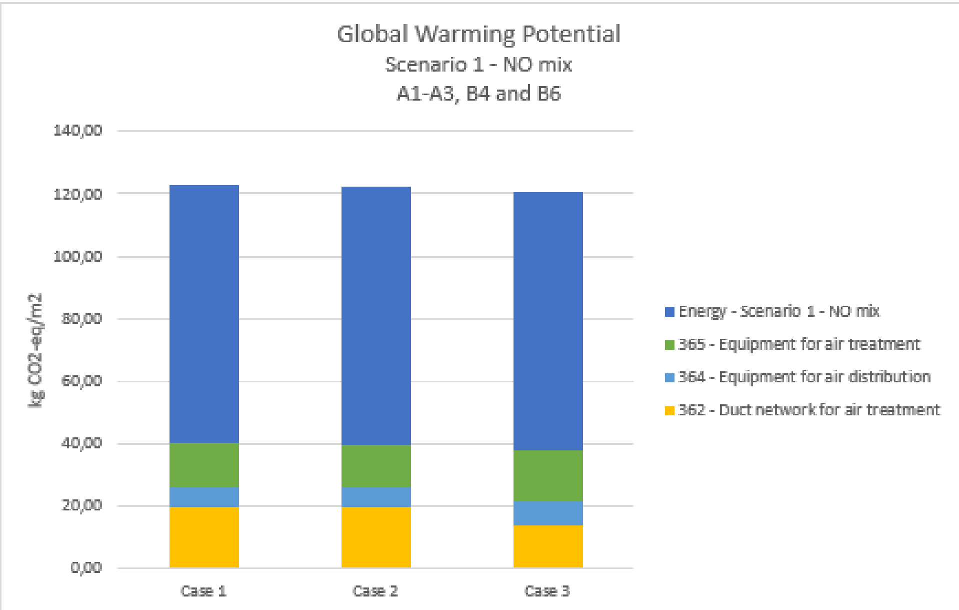

Figure 21. Results from the calculation of Global Warming Potential in kg CO_2-eq/m^2 BTA for A1-A3, Product, B4, Replacement, and B6, Operational energy use, for the three cases. B6, Operational energy use, with Scenario 1 – NO mix. Divided in building element categories according to NS 3451:2022.

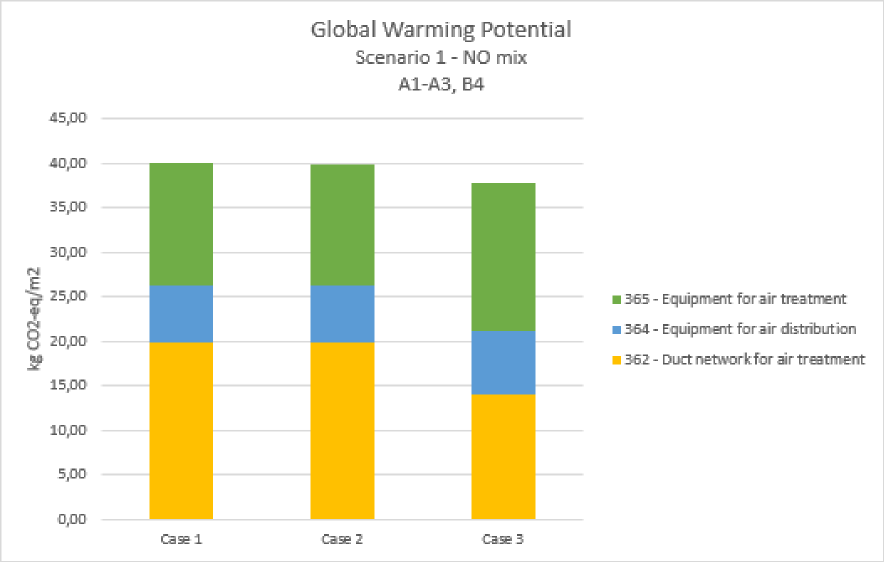

Figure 22. Results from the calculation of Global Warming Potential in kg CO_2-eq/m² BTA for A1-A3, Product, and B4, Replacement. Divided in building element categories according to NS 3451:2022.

4.2.1 Case 1 and Case 2

When comparing case 1 and case 2, with the difference in the use of the building for the first 20 years, the GWP presented in Table 29 are almost equal. Case 2 has a lower occupancy factor for the first period which gives a lower air volume in the energy simulation and a less heavy AHU.

The AHU for the first period in case 2 has a 167 kg lower weight than the AHU in case 1. When using kg as a scaling factor for the GWP the less heavy AHU gives a reduction in GWP of 0,17 kg CO_2-eq/m². When looking at B6, Operational energy use, the influence of the lower air volume for the first 20 years is very low. The difference in yearly delivered energy from the IDA ICE simulations is 1492 kWh/year which gives a yearly reduction in GWP calculated with Scenario 1 of 0,01 kg CO_2-eq/m² /year. Calculated over the whole analyse time of 60 years and with the change of AHU, to the same dimension as in case 1, after 20 years it gives a reduction in B6, Operational Energy use, of 0,11 kg CO_2-eq/m².

The use of a lower occupancy factor and a smaller AHU for the first 20 years in case 2 gives a total reduction of 0,28 kg CO_2-eq/m², less than 0,3%, for module A1-A3, B4 and B6 compared to case 1.

Table 29. Results from the calculation of Global Warming Potential in kg CO_2-eq/m² BTA for A1-A3, Product, B4, Replacement and B6, Operational energy use, for case 1 and 2. B6, Operational energy use, with Scenario 1 – NO mix. The GWP is divided in building element categories according to NS 3451:2022.

Global Warming Potential for A1-A3, B4 and B6 Scenario 1 – NO mix kg CO_2-eq/m² BTA	Unit	Case 1	Case 2
Energy – Scenario 1 – NO mix	kg CO_2-eq/m²	82,80	82,69
365 – Equipment for air treatment	kg CO_2-eq/m²	13,68	13,51
364 – Equipment for air distribution	kg CO_2-eq/m²	6,54	6,54
362 – Duct network for air treatment	kg CO_2-eq/m²	19,79	19,79
GWP Total - Scenario 1 – NO mix	**kg CO_2-eq/m²**	**122,81**	**122,53**

4.2.2 Case 1 and Case 3

When comparing the GWP for case 1 and case 3, the calculations give a difference of 2,06 kg CO_2-eq/m^2 where case 3 is 1,7% smaller than case 1. However, when comparing on building elements level the results show larger discrepancy. Table 30 present the GWP for A1-A3, B4 and B6 with Scenario 1 for case 1 and case 3 divided in building element category according to NS 3451:2022.

In category 365, Equipment for air treatment, case 3 has a 2,78 kg CO_2-eq/m^2 higher GWP than case 1. Building element category 365 contains of the Air Handling Units. In case 1 with centralized AHU it is used one AHU with a weight of 4477 kg and a GWP of 22 568,5 kg CO_2-eq in A1-A3, Product. For case 3 with decentralized AHU, three AHU with a weight of 1796 kg each and a total GWP of 27 160 kg CO_2-eq in A1-A3 for all three. When also calculating with B4, Replacement, the total difference between the AHU is 2,78 kg CO_2-eq/m^2 and case 3 with decentralized are having the highest GWP for the AHU.

Building element category 364, Equipment for air distribution, contains of dampers for VAV systems, air terminals and sound attenuators. The difference between case 1 and case 3 is 0,69 kg CO_2-eq/m^2 where case 3 has the highest GWP. The main contributor to the difference is the sound attenuators in connection to the AHU. It is not performed a sound calculation to verify the dimension of the estimated sound attenuator, however the decentralized system with 3 AHU will have three times higher need for sound attenuator regardless of the dimension.

The largest difference between case 1 and case 3 is in building element category 362, Duct network for air treatment. Building category 362 contains all ducts, tees, bends, and grilles. The distribution network out in the floor is almost equal between case 1 and case 3. The main contributor to the difference is ducts to AHU and the outdoor and exhaust ducts. Case 1, with the AHU in floor 1, are having 120m with duct with several bends from the main floors to the AHU and outdoor/exhaust meanwhile case 3 are only having 60m duct with less bends and smaller dimension. The difference between case 1 and case 3 is 5,79 kg CO_2-eq/m^2 and case 1 is higher than case 3.

The contribution from building element category 362 is depending on the floor plan of the building. For the case with centralized system the location of the AHU plant room and the location of the intake of outdoor air and exhaust air are strongly contributing to the GWP from category 362. For the case with decentralized system the location of the intake of outdoor air and exhaust also contributes to the GWP for category 362. In case 3 the intake of outdoor air and exhaust air are placed on the external wall, however if the floor plan or the surroundings of the building makes it necessary to have the intake of outdoor air and exhaust air on the roof the impact from 362 will increase.

The calculation of GWP from energy in B6 gives a difference of 0,27 kg CO_2-eq/m^2 where case 3 with three AHU and an occupancy factor of one gives the highest GWP.

To summarize, the difference in GWP for case 1 and case 3 is 2,06 kg CO_2-eq/m^2 where case 3 has the smallest GWP. The main contributors to difference are the ducts from main floors to AHU plant room and the outdoor and exhaust ducts.

Table 30. Results from the calculation of Global Warming Potential in kg CO_2-eq/m^2 BTA for A1-A3, Product, B4, Replacement, and B6, Operational energy use, for case 1 and 3. B6, Operational energy use, with Scenario 1 – NO mix. The GWP is divided in building element categories according to NS 3451:2022.

Global Warming Potential for A1-A3, B4 and B6 **Scenario 1 – NO mix** kg CO_2-eq/m^2 BTA	**Unit**	**Case 1**	**Case 3**
Energy – Scenario 1 – NO mix	kg CO_2-eq/m^2	82,80	83,07
365 – Equipment for air treatment	kg CO_2-eq/m^2	13,68	16,46
364 – Equipment for air distribution	kg CO_2-eq/m^2	6,54	7,23
362 – Duct network for air treatment	kg CO_2-eq/m^2	19,79	14,00
GWP Total - Scenario 1 – NO mix	**kg CO_2-eq/m^2**	**122,81**	**120,75**

When comparing a centralized system with a decentralized system it is also important to look at the space that is used as AHU plant room. Case 3 with decentralized system is using space in the office area as AHU plant room meanwhile case 1 and case 2 with the Air Handling Unit placed in floor 1 which is a basement floor. Case 1 and case 2 are using space that could not been used for office area due to daylight regulation and other parameters. It is important to evaluate the impact and how to compensate for the occupied space regarding GWP. Calculation shows that the AHU plant room need to be at least 80m^2 for case 1 and case 2. For case 3 the AHU plant room needs to be at least 44m^2 for each AHU, in total 132m^2. The need of floor area for AHU plant room in case 3 is 65% larger than in case 1 and case 2.

A decentralized system with the AHU placed in the same floor as the office area will have a different need for sound insulation of the AHU plant room than an AHU plant room placed in a basement. The insulation will contribute to the total GWP of the building and needs to be taking into consideration when choosing between a centralized and decentralized system.

4.3 Air Handling Units

The Air Handling Units contributes to a large part of the total GWP for the ventilation system. Results from calculation done for the cases in this study gives a contribution of the AHU of 11% for case1 and 2 and 14% for case 3. It is chosen to use the Gold RX from Swegon AS for AHU. The EPD, S-P-05063 Gold RX 011/012 – Silver C RX 011/012 is used for calculation of the Global Warming Potential for Air Handling Units. It is used kg as a scaling factor since the EPD only gives GWP data for one dimension and needs to be calculated for other dimensions. The EPD for Gold RX 011/012 – Silver C RX 011/012 specifies that it can only be used for Gold RX 011/012, Silver C RX 011/012, as well as products with similar configuration and weight [24], however in absence of EPD for larger AHU the EPD is used for all dimensions.

An AHU can be delivered with lots of different combination of fans, heat exchanger, filters and heating and cooling solutions, therefore it is a lot of different combinations of material percentage. Using an EPD for one dimension and scaling the GWP data using kg can be uncertain. The absence of available EPD data for Air Handling Units in larger dimensions and different configuration is a limitation when performing a LCA for HVAC systems. The result of the calculation for module A1-A5 and C1-C4 might be influenced by the lack of EPDs for larger AHU. The change in material percentage in the AHU is not considered when scaling between dimensions of the AHU by weight. For example, the frame of AHU might have the same material thickness for several dimensions of the AHU, but when scaling by weight the material thickness is increased or decreased linear with the weight.

When calculation the total GWP for module A1-A3, B4 and B6 for each case, presented earlier in this chapter, only the GWP data in module A1-A3 from the EPD S-P-05063 Gold RX 011/012 – Silver C RX 011/012 is used. The following section compares and evaluates the AHU with GWP for all modules available in the EPD, A1-A5 and C1-C4, and over a 20 year period.

When choosing Air Handling Units for the three cases in this thesis the design tool from Swegon AS is used. Three AHU is chosen for each case and the weight of the AHU, given by the design tool, is used to calculate the GWP for module A1-A5 and C1-C4 with GWP data from the EPD S-P-05063 Gold RX 011/012 – Silver C RX 011/012. Module B6 is calculated with the delivered energy from a yearly Delivered Energy simulation in IDA ICE and with the CO_2-emission factor for Scenario 1 – NO mix. The simulation is done with the Specific Fan Power, SFPe, from the design tool and the air volume for each case. It is not possible to separate energy used in the ventilation system from the energy used for heating and cooling, therefore the amount of energy is high. Since only parameters connected to the ventilation system is changed between the simulation, the difference between the simulations represents the impact of the ventilation system. It is chosen to evaluate the AHU over a 20-year period due to the Estimated Service lifetime of the AHU is 20 years.

Figure 23 presents the three Air Handling Units chosen for evaluation in case 1, Figure 24 presents the AHU chosen for case 2 and Figure 25 present the AHU for case 3. The figures present the GWP for module A1-A5 and C1-C4 and B6. B6 is for all Delivered energy to the building excluding energy for lighting and equipment for a period of 20 years. A1-A5 and C1-C4 is for one AHU in case 1 and case 2 and for three AHU in case 3 since the decentralized solution in case 3 are using three AHU.

The result from the evaluation process for all three cases shows that when choosing a small AHU with low weight, the GWP for module A1-A5 and C1-C4 decrease. With a smaller AHU the SFPe increases and the GWP for module B6 increases. However, when calculating the GWP for all modules the difference between the AHU is small.

TEK17 §14-2 regulates the energy framework of an office building to be 115 kWh/m^2 [42] and it is based on a calculation with the SFPe for the AHU to be ≤1.5 kW/(m^3/s) [35]. The energy framework limits the opportunity to choose an AHU only based on the lowest GWP in this case, however it is interesting to study the correlation between the dimension of AHU, SFP and GWP.

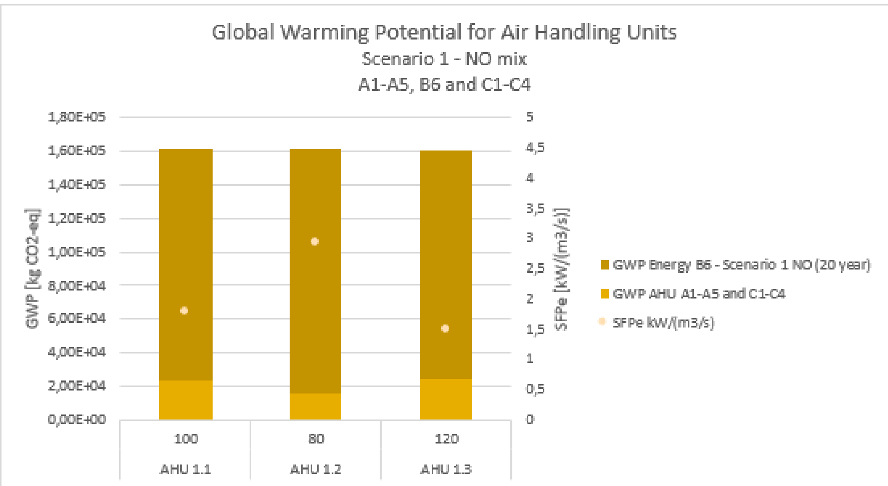

Figure 23. Results of the Global Warming Calculation for the three AHU in case 1 for A1-A5, Product and Construction, B6, Operational energy use, and C1-C4, End of life, over a 20-year evaluation period. B6, Operational energy use with Scenario 1 – NO mix.

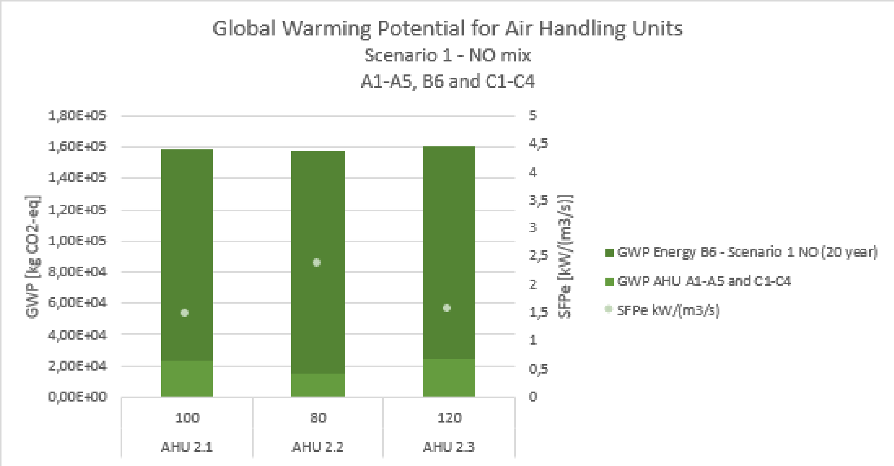

Figure 24. Results of the Global Warming Calculation for the three AHU in case 2 for A1-A5, Product and Construction, B6, Operational energy use, and C1-C4, End of life, over a 20-year evaluation period. B6, Operational energy use, with Scenario 1 – NO mix.

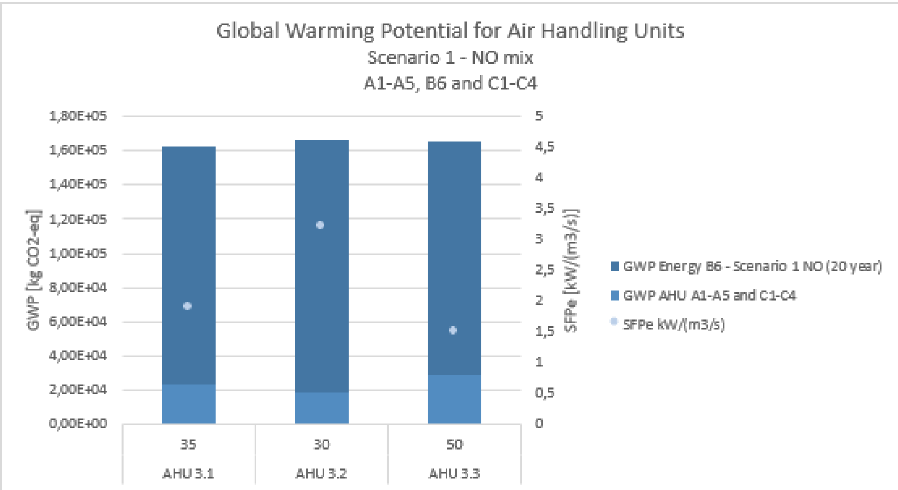

Figure 25. Results of the Global Warming Calculation for the three AHU in case 3 for A1-A5, Product and Construction, B6, Operational energy use, and C1-C4, End of life, over a 20-year evaluation period. B6, Operational energy use, with Scenario 1 – NO mix.

4.4 Sensitivity check

A LCA study contains of data from several sources and inputs, therefore it will always be uncertainty in the study. A sensitivity check shall be provided according to NS 3720:2018 *Method for greenhouse gas calculations for buildings.* The purpose with the sensitivity check is to investigate the sensitivity of the result in relation to the data quality and prerequisites [10].

4.4.1 Quality of LCA data

The quality of the LCA data is of great important for the result. In the result file from the REVIT plugin it is not possible to easily read out the source of the GWP data. The source is listed in a separate database but not in the result file. This makes it difficult to estimate the amount of data from each quality level. To have a large amount of data from quality level 2 makes an uncertainty in the calculation.

4.4.2 Scaling of data for Air Handling Units

Since there is lack of LCA data for Air Handling Units in different dimensions and for the time only two available EPD for AHU in Norway, there are uncertainty in the calculation of GWP for AHU. In this case the calculation of GWP for the AHU is done by scaling from one EPD, with weight as scaling factor. It will always be uncertainty with scaling GWP of a complex product like AHU due to different material percentage and configurations.

4.4.3 Lifetime for components

Several components in a ventilation system are having short lifetime compared the lifetime of the building. A short lifetime has an influence on module B4, Replacement, therefore an uncertainty in the lifetime makes uncertainties to the result.

As example, the reference service lifetime of the AHU is not specified in the EPD, however the EPD indicates an expected time to be used of 20 years [24] and the report *Levetider i praksis – Prinsipper og bruksområder*, by Multiconsult gives a functional life time for AHU of 16-20 years [45]. Based on the indication in the EPD and the report, it is chosen to use 20 years as lifetime for the AHU. A different lifetime of the AHU will have an impact on the result.

The EPD NEPD-4048-3076-EN for LEO VAV dampers declares a Reference service life for the product of 20 years [50] and the Multiconsult database declares a lifetime for the same product of 15 years. It is chosen to use 15 years in this LCA since data from Multiconsult database is the priority of data.

4.4.4 B6, Operational energy use

B6, Operational energy use has the largest contribution to the result in all cases. The calculation of delivered energy is based on a simplification of the building which makes an uncertainty to the calculation.

4.5 Uncertainty and Sources of error

A LCA study contains of many parts and calculations, it will therefore always have some uncertainty and source of errors. The bullet points below highlight some of the uncertainty and source of errors for this calculation:

- All delivered energy used in the calculation of GWP for B6 has been considered as electrical and two different CO_2 emission factors for electrical energy have been used for calculation. If the source of the energy was taken into account in the calculation of the GWP for B6, the result would have been different. However, when comparing the cases, the impact of the simplification is considered to be small.
- The model used for delivered energy calculations in IDA ICE is a simplification of the building. The simplified model visualizes the consequences of the changed parameter between the cases, but it will not show the actual delivered energy demand of the building.
- The model in IDA ICE is model with a larger floor area then the REVIT model and the air volume calculation. When building the model and calculating the input for the air flow in IDA ICE, the gross area was used as floor area. This results in a deviation of 0,6% in yearly delivered energy to the building and have no significant impact on the conclusion since it is equal for all cases.
- The model in REVIT is created with the purpose of comparing the cases and to achieve the amount of material for calculation of the GWP. Other models and other buildings will have a different GWP/BTA depending on the choice of components and the use of the building.
- The GWP calculation for the Air Handling Units is done by scaling data from an EPD with data for only one dimension of an AHU. The material percentages in an AHU will always vary due to many different configurations of the AHU and it makes an uncertainty in the calculation.
- The calculation of GWP/m^2 is done with a BTA that does not includes all areas. When including the missing areas, all results of GWP/m^2 will be 2,7% lower. There will be no consequences when comparing the cases or the conclusion.

- The risk for recycling of air from exhaust to outdoor air intake is not considered. Mitigation for reducing the risk of pollution from exhaust air might influence the results of the LCA.

5 Conclusions

This chapter will present the conclusion of this master thesis by answering the research questions from Chapter 1, Introduction. This chapter will also present suggestions for further research.

Calculations and results in this study cannot be generalized for all ventilation system but is to be used for comparing cases in this study and to visualize trends and indications. A calculation of the Global Warming Potential for a system is strictly depending on the layout and the use of the building.

5.1 Main findings

Is there any difference in Global Warming Potential from a Centralized air treatment system or a Decentralized air treatment system for an office building?

The result from calculation of the Global Warming Potential in this thesis with case 1, centralized system, and case 3, decentralized system, shows that the difference between the two system is small. Calculated with Scenario 1 – NO energy mix, the Global Warming Potential for module A1-A3, Product, B4, Replacement, and B6, Operational energy use, is 122,81 kg CO_2-eq/m^2 for case 1 and 120,75 kg CO_2-eq/m^2 for case 3. The Global Warming Potential for case 3 is 1,7% lower than in case 1.

Which parts of the systems are contributing to the difference in Global Warming Potential?

The difference in Global Warming Potential between the centralized system and the decentralized system is only 1,7% when comparing module A1-A3, Product, B4, Replacement, and B6, Operational energy use. When analysing the result on building element level according to NS 3451:2022 *Table of building elements and table of codes for systems in building with associated outdoor areas* the result shows a discrepancy on building elements level. The largest discrepancy is in building element category 362 and 365.

Building element category 362, Duct network for air treatment, is having the largest difference between the cases, where case 3 is 29% lower than case 1. The main contributor is length and size of the main ducts between the floors, Air Handling Units and outdoor and exhaust air intake. The lengths of the main ducts are strictly depending on the layout and the floor plan of the building. Also, the surroundings of the building set a limitation on where to place intake for outdoor and exhaust air.

The difference in building element category 365, Equipment for air treatment is 20%. Where case 3 with 3 Air Handling Units are having a 20% higher Global Warming Potential than case 1 with only 1 Air Handling Unit. The demand of floor area for AHU plant room is 65% higher for case 3 than case 1. It is important to evaluate the impact on Global Warming Potential of the demand for floor area and type of floor area when choosing between systems.

How does the choice of Air Handling Unit regarding dimension and Specific Fan Power contributes to the Global Warming Potential?

Results from calculations of the Global Warming Potential in this thesis show that it is important to evaluate both the embodied impacts from material and operational impact from energy when evaluation the Global Warming Potential for an AHU. The result on Global Warming Potential for the Air Handling Units investigated in this thesis shows that when selecting a larger AHU with lower SFP, the total Global Warming Potential over one lifecycle of the AHU is almost equal with selection of a smaller AHU with higher SFP, when energy is included in the LCA.

Is it a significant impact on the Global Warming Potential if the building uses a smaller Air Handling unit and lower air volume during a part of the lifetime?

Case 2 in this thesis represents a building with a lower occupancy factor during the first 20 years of the lifetime of the building. When comparing case 2 and case 1 the different in the Global Warming Potential for module A1-A3, Product, B4, Replacement, and B6, Operational energy use, is less than 0,3% calculated with Scenario 1 – NO energy mix.

5.2 Recommendations

Below is a list of things to evaluate when choosing between a centralized and decentralized ventilation system with respect of impacts on Global Warming Potential. The list is based on the results from calculation of GWP in this thesis.

- Which system to prefer, a centralized or a decentralized system, depends on the layout of the building. It depends on the distance to AHU plant room, distance to intake and layout of shafts. It needs to be done a LCA for each project to find the best solution for that specific building.
- When choosing a decentralized system, it is important to evaluate the consequences on the Global Warming Potential of the extra space needed to AHU plant room.
- It is important to evaluate both embodied and operational impacts when evaluating the Global Warming Potential of an Air Handling Units.

5.3 Further research

This thesis is limited in both time and lack of data, and it only looks at a small part of LCA for HVAC systems. This is an important area of research and below are some suggestions of further research:

- Include all modules in the Life Cycle Assessment.
- Include other impacts than Global Warming Potential in the Life Cycle Assessment.
- Include heating and cooling in the LCA and investigate the whole HVAC system.
- Investigate how to calculate and compensate for the additional space needed for AHU plant room in a decentralized solution.
- Develop a tool or database that easily can locate and update EPD data.

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APPENDIX

A - Air volume calculations on room level

B - Air volume calculations for total air volume

C - Estimation of ducts and grilles for outdoor and exhaust

D - Pressure drop estimation for duct systems

E - Datasheet for AHU

F - Calculation of floor area for AHU

G - Delivered Energy Reports

H - Components and lifetime

A - Air volume calculations on room level

Air volume calculations on room level for one floor. With air volume according to TEK17.

Table 31. Air volume calculations on room level for one floor.

											Room level		
											TEK 17 regulations		
						Source:	TEK 17	TEK 17	TEK 17	TEK 17			
Floor	Room nr	Room function	Primary/Secondary	CAV/VAV	Area	Number of persons	Air volum per person [(m3/h)/person]	Air volum per sqr meter [m3/h)/m2]	Air volum per sqr meter - night [m3/h)/m2]	Pre defined value from TEK 17 [m3/h]	Qmin [m3/h]	Qmax [m3/h]	Qnight [m3/h]
3	1	Open office area 1	Primary	VAV	397	32	26	2,5	0,7		992,5	1824,5	277,9
3	2	Meeting room	Primary	VAV	16,6	5	26	2,5	0,7		41,5	171,5	11,62
3	3	Stairs	Secondary	CAV		0	26	2,5	0,7		0	0	0
3	4	Meeting room	Primary	VAV	14,3	3	26	2,5	0,7		35,75	113,75	10,01
3	5	Meeting room	Primary	VAV	25,2	8	26	2,5	0,7		63	271	17,64
3	6	Silent room	Primary	VAV	6,1	2	26	2,5	0,7		15,25	67,25	4,27
3	7	Silent room	Primary	VAV	6,1	2	26	2,5	0,7		15,25	67,25	4,27
3	8	Meeting room	Primary	VAV	13,3	5	26	2,5	0,7		33,25	163,25	9,31
3	9	Meeting room	Primary	VAV	19,9	8	26	2,5	0,7		49,75	257,75	13,93
3	10	Elevator	Secondary	CAV		0	26	2,5	0,7	30	0	0	0
3	11	Meeting room	Primary	VAV	30,6	12	26	2,5	0,7		76,5	388,5	21,42
3	12	WC	Secondary	CAV	28,5	0	26	2,5	0,7	36	221,25	221,25	19,95
3	13	Open office area 2	Primary	VAV	340	48	26	2,5	0,7		850	2098	238
3	14	Meeting room	Primary	VAV	22,7	6	26	2,5	0,7		56,75	212,75	15,89
3	15	Meeting room	Primary	VAV	17,5	5	26	2,5	0,7		43,75	173,75	12,25
3	16	Meeting room	Primary	VAV	17,5	5	26	2,5	0,7		43,75	173,75	12,25
3	17	Meeting room	Primary	VAV	28,9	10	26	2,5	0,7		72,25	332,25	20,23
3	18	Meeting room	Primary	VAV	26,5	10	26	2,5	0,7		66,25	326,25	18,55
3	19	Open office area 3	Primary	VAV	396,5	54	26	2,5	0,7		991,25	2395,25	277,55
3	20	Meeting room	Primary	VAV	19	6	26	2,5	0,7		47,5	203,5	13,3
3	21	Meeting room	Primary	VAV	16,8	4	26	2,5	0,7		42	146	11,76
3	22	Meeting room	Primary	VAV	12	3	26	2,5	0,7		30	108	8,4
3	23	Meeting room	Primary	VAV	21,8	8	26	2,5	0,7		54,5	262,5	15,26
3	24	WC	Secondary	CAV	21,3	0	26	2,5	0,7	36	139,75	139,75	14,91
3	25	Meeting room	Primary	VAV	15,9	6	26	2,5	0,7		39,75	195,75	11,13
3	26	Meeting room	Primary	VAV	10	3	26	2,5	0,7		25	103	7
3	27	Meeting room	Primary	VAV	11,8	4	26	2,5	0,7		29,5	133,5	8,26
3	28	Corridor	Secondary	VAV	46,3	0	26	2,5	0,7		115,75	115,75	32,41
3	29	Stairs	Secondary	CAV		0	26	2,5	0,7		0	0	0
3	30	Elevator	Secondary	CAV		0	26	2,5	0,7	30	0	0	0
3	31	Stairs	Secondary	CAV		0	26	2,5	0,7		0	0	0
3	32	Technical shaft	Secondary	CAV	3	0	26	2,5	0,7		7,5	7,5	2,1
3	33	Technical shaft	Secondary	CAV	2	0	26	2,5	0,7		5	5	1,4
					1587,1			**SUM:**			**4204**	**10678**	**1111**

Room number used in calculations of air volume:

Figure 26. Room number used in calculations of air volume. The project with developing Bøkkerveien 1-3 is in an early phase and changes will occur to the project and floorplan. Figure with permission from Höegh Eiendom AS. [33]

B - Air volume calculations for total air volume

Air volume calculation on AHU level for each case:

Table 32. Air volume calculation on AHU level for each case.

	Room level			AHU level						
	TEK 17 regulations			Case 1		Case 2			Case 3	
				Ofz:	0,907068	Ofz:	0,699229	0,907068	Ofz:	1
				S:	0,9436573	S:	0,8176488	0,9436573	S:	1
Floor	Qmin [m3/h]	Qmax [m3/h]	Qnight [m3/h]	Qmin [m3/h]	QDCV [m3/h]	Qmin [m3/h]	QDCV low [m3/h]	QDCV high [m3/h]	Qmin [m3/h]	QDCV [m3/h]
1	4204	10678	1111	4204	10077	4204	8731	10077	4204	10678
2	4204	10678	1111	4204	10077	4204	8731	10077	4204	10678
3	4204	10678	1111	4204	10077	4204	8731	10077	4204	10678
Total/AHU	**12613**	**32035**	**3333**	**12613**	**30230**	**12613**	**26193**	**30230**	**4204**	**10678**

C - Estimation of ducts and grilles for outdoor and exhaust

Estimation of ducts for outdoor and exhaust air. Case 3 is multiplied with three (3 AHU) when calculating the GWP.

Table 33. Estimation of ducts for outdoor and exhaust air.

Ducts for outdoor air and exhaust air			
	Case 1	**Case 2**	**Case 3**
Length [m]	50	50	10
Dimension [mm x mm]	950x1300	950x1300	500x900

Estimation of grilles for outdoor and exhaust air. Case 3 is multiplied with three (3 AHU) when calculating the GWP.

Table 34. Estimation of grilles for outdoor and exhaust air.

Grilles for outdoor air and exhaust air			
	Case 1	**Case 2**	**Case 3**
Dimension [mm x mm]	950x1300	950x1300	500x900
Size [m2]	1,235	1,235	0,45

D - Pressure drop estimation for duct systems

Estimation of pressure drop with formula from SN-NSPEK 3031:2012 Appendix F [43].

$$\Delta p_{ext,s} = \Delta p_{reg} + \left(\Delta p_{ext,dim} - \Delta p_{reg}\right) * r^2 \quad [Pa] \quad (4)$$

$$r = \frac{Q_{red}}{Q_{dim}} \quad [-] \quad (5)$$

r	*Part load factor for reduction of air volume in relation to dimensioning air volume*	-
$\Delta p_{ext,s}$	*Pressure drop over ductsystem with reduced air volume*	*Pa*
Δp_{reg}	*Lowest possible pressure drop over the ductsystem as results of VAV regulation. From table F.7 in SN-NSPEK 3031:2021*	*Pa*
$\Delta p_{ext,dim}$	*Pressure drop over ductsystem with dimensioning air volume. From table F.7 in SN-NSPEK 3031:2021*	*Pa*
Q_{red}	*Reduced air volume*	*m^3/h*
Q_{dim}	*Dimensioning air volume*	*m^3/h*

Results from estimation:

Table 35. Results from estimation.

		Case 01	Case 02		Case 03
	Unit		**Low**	**High**	
r		0,9436554	0,817637	0,9436554	1
DeltaP reg	Pa	100	100	100	100
DeltaP ext,dim	Pa	250	250	250	250
Qred	m3/h	30230	26193	30230	10678
Qdim	m3/h	32035	32035	32035	10678
DeltaP ext,s	**Pa**	**234**	**200**	**234**	**250**

E - Datasheet for AHU

Case 1 AHU 1.1 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 1 - AHU 01 - Design data

Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407576

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

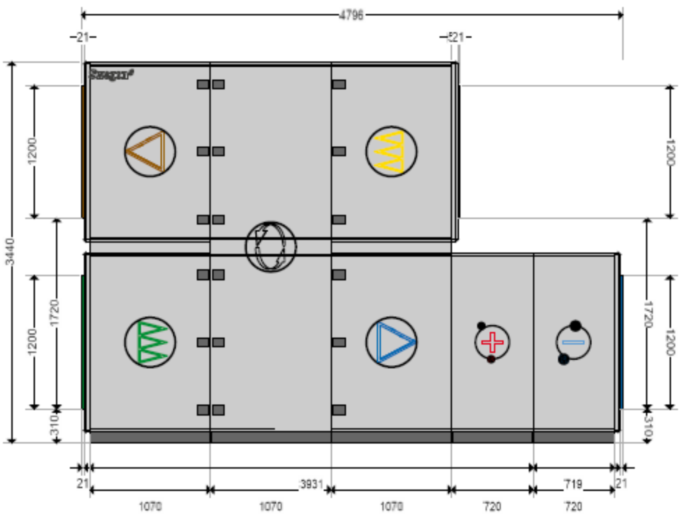
Dimensioning data	Case 1 - AHU 01		
Unit size		100	
Air density		1.200	kg/m³
Supply air flow		8.400	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	184	Pa
Extract air flow		8.400	m³/s
Static pressure drop	Extract air duct	184	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.66	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.78	kW/(m³/s)
Dry temperature efficiency of supply air, winter		81.8	%
Eurovent Energy Efficiency Class	Summer: A+ ⊆ 2020	Winter: A+	2016
Eurovent; Fs_Pref:	Summer: 0.98	Winter:	0.98
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

EUROVENT CERTIFIED PERFORMANCE ENERGY EFFICIENCY

ErP fulfillment

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	100	
Unit weight	4,357	kg
Duct Component Weight	0	kg
Length, max	4,796	mm
Height, max	3,440	mm
Width, max	3,340	mm

Connection size		
outdoor air	2,400 x 1,200	mm
supply air	2,400 x 1,200	mm
extract air	2,400 x 1,200	mm
exhaust air	2,400 x 1,200	mm

Project: Master
Unit name: Case 1 - AHU 01
Unit ID: AD-10001407576
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 1 AHU 1.2 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 1 - AHU 01 - Design data

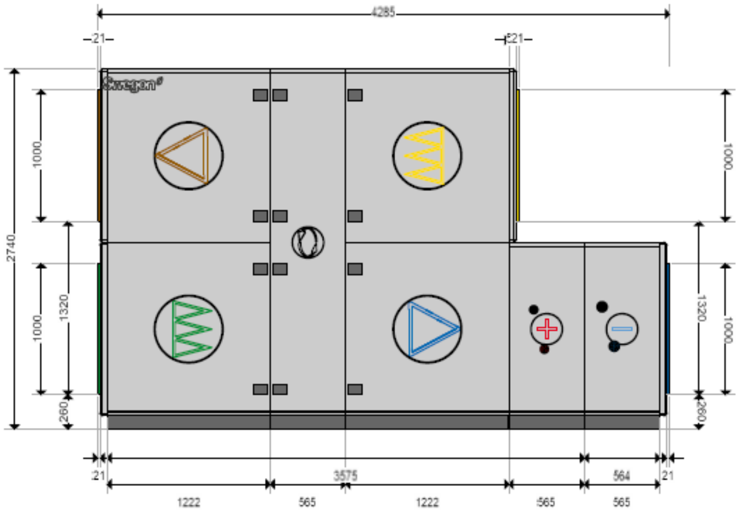
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407576

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 1 - AHU 01		
Unit size		080	
Air density		1.200	kg/m³
Supply air flow		8.400	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	184	Pa
Extract air flow		8.400	m³/s
Static pressure drop	Extract air duct	184	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	2.71	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	2.94	kW/(m³/s)
Dry temperature efficiency of supply air, winter		78.4	%
Eurovent Energy Efficiency Class	Summer: C C 2020	Winter: C	2016
Eurovent; Fs_Pref:	Summer: 0.95	Winter:	0.95
ErP Commission Regulation (EU) No 1253/2014		Not Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	080	
Unit weight	2,910	kg
Duct Component Weight	0	kg
Length, max	4,285	mm
Height, max	2,740	mm
Width, max	2,637	mm

Connection size		
outdoor air	1,800 x 1,000	mm
supply air	1,800 x 1,000	mm
extract air	1,800 x 1,000	mm
exhaust air	1,800 x 1,000	mm

Project: Master
Unit name: Case 1 - AHU 01
Unit ID: AD-10001407576
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 1 AHU 1.3 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 1 - AHU 01 - Design data

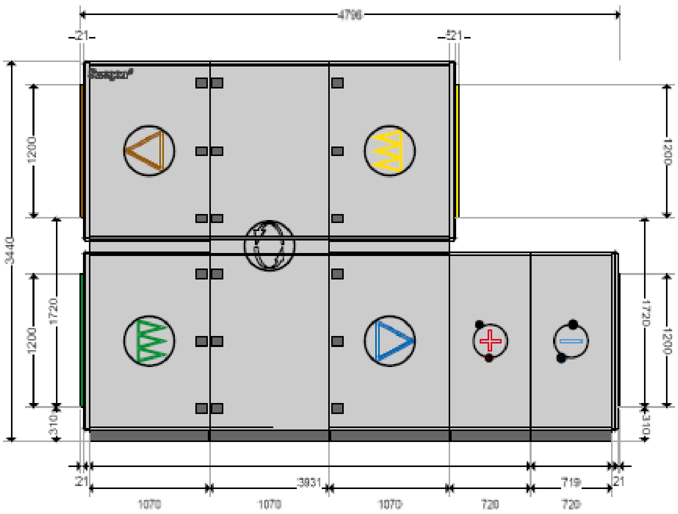
Date: 28/04/2023
32 / 1.0.20230405.1122830
Unit ID: AD-10001407576

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 1 - AHU 01		
Unit size		120	
Air density		1.200	kg/m^3
Supply air flow		8.400	m^3/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	184	Pa
Extract air flow		8.400	m^3/s
Static pressure drop	Extract air duct	184	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.37	$kW/(m^3/s)$
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.49	$kW/(m^3/s)$
Dry temperature efficiency of supply air, winter		77.9	%
Eurovent Energy Efficiency Class	Summer: A ⊆ 2020	Winter: A	2016
Eurovent; Fs_Pref:	Summer: 0.86	Winter:	0.86
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

AHU Design
Sketch: Inspection side



GOLD FRX		
Unit size	120	
Unit weight	4,477	kg
Duct Component Weight	0	kg
Length, max	4,796	mm
Height, max	3,440	mm
Width, max	3,340	mm

Connection size		
outdoor air	2,400 x 1,200	mm
supply air	2,400 x 1,200	mm
extract air	2,400 x 1,200	mm
exhaust air	2,400 x 1,200	mm

Project: Master
Unit name: Case 1 - AHU 01
Unit ID: AD-10001407576
32 / 1.0.20230405.1122830
Date: 28/04/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 2 AHU 2.1 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 2 - AHU 1 - Design data

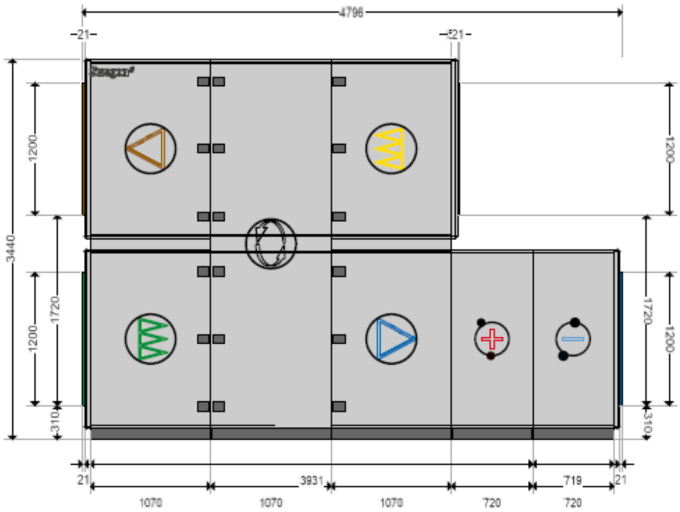
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407732

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 2 - AHU 1		
Unit size		100	
Air density		1.200	kg/m³
Supply air flow		7.300	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	150	Pa
Extract air flow		7.300	m³/s
Static pressure drop	Extract air duct	150	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.38	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.50	kW/(m³/s)
Dry temperature efficiency of supply air, winter		82.7	%
Eurovent Energy Efficiency Class	Summer: A+ ⊊ 2020	Winter: A+	2016
Eurovent; Fs_Pref:	Summer: 0.83	Winter:	0.83
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	100	
Unit weight	4,310	kg
Duct Component Weight	0	kg
Length, max	4,796	mm
Height, max	3,440	mm
Width, max	3,340	mm

Connection size		
outdoor air	2,400 x 1,200	mm
supply air	2,400 x 1,200	mm
extract air	2,400 x 1,200	mm
exhaust air	2,400 x 1,200	mm

Project: Master
Unit name: Case 2 - AHU 1
Unit ID: AD-10001407732
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Swegon

Case 2 AHU 2.2 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 2 - AHU 1 - Design data

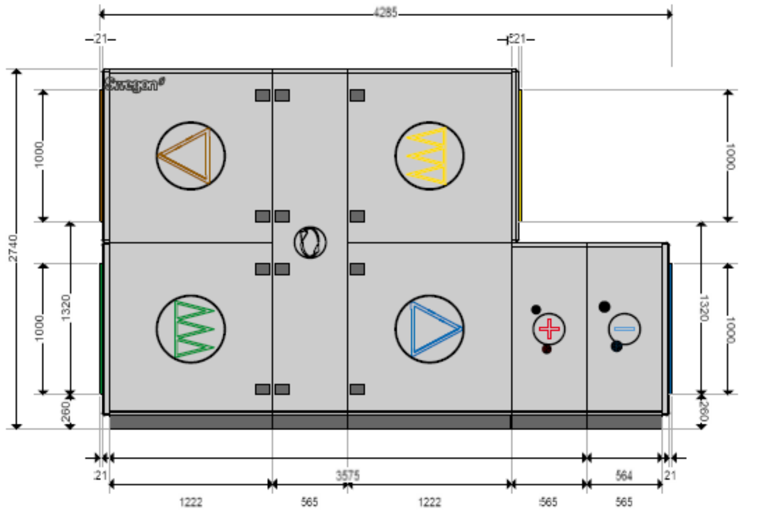
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407732

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 2 - AHU 1		
Unit size		080	
Air density		1.200	kg/m³
Supply air flow		7.300	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	150	Pa
Extract air flow		7.300	m³/s
Static pressure drop	Extract air duct	150	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	2.18	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	2.38	kW/(m³/s)
Dry temperature efficiency of supply air, winter		79.4	%
Eurovent Energy Efficiency Class	Summer: B 2020	Winter: B	2016
Eurovent; Fs_Pref:	Summer: 0.96	Winter:	0.96
ErP Commission Regulation (EU) No 1253/2014		Not Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	080	
Unit weight	2,868	kg
Duct Component Weight	0	kg
Length, max	4,285	mm
Height, max	2,740	mm
Width, max	2,637	mm

Connection size		
outdoor air	1,800 x 1,000	mm
supply air	1,800 x 1,000	mm
extract air	1,800 x 1,000	mm
exhaust air	1,800 x 1,000	mm

Project: Master
Unit name: Case 2 - AHU 1
Unit ID: AD-10001407732
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 2 AHU 2.3 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 2 - AHU 1 - Design data

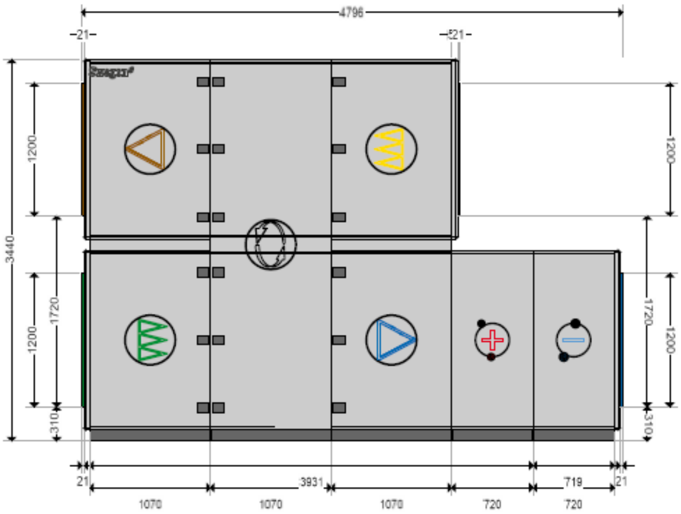
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407732

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 2 - AHU 1		
Unit size		120	
Air density		1.200	kg/m³
Supply air flow		7.300	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	150	Pa
Extract air flow		7.300	m³/s
Static pressure drop	Extract air duct	150	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.41	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.57	kW/(m³/s)
Dry temperature efficiency of supply air, winter		82.7	%
Eurovent Energy Efficiency Class	Summer: A+ C 2020	Winter: A+	2016
Eurovent; Fs_Pref:	Summer: 0.86	Winter:	0.86
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	120	
Unit weight	4,510	kg
Duct Component Weight	0	kg
Length, max	4,796	mm
Height, max	3,440	mm
Width, max	3,340	mm

Connection size		
outdoor air	2,400 x 1,200	mm
supply air	2,400 x 1,200	mm
extract air	2,400 x 1,200	mm
exhaust air	2,400 x 1,200	mm

Project: Master
Unit name: Case 2 - AHU 1
Unit ID: AD-10001407732
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 3 AHU 3.1 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 3 - AHU 1 - Design data

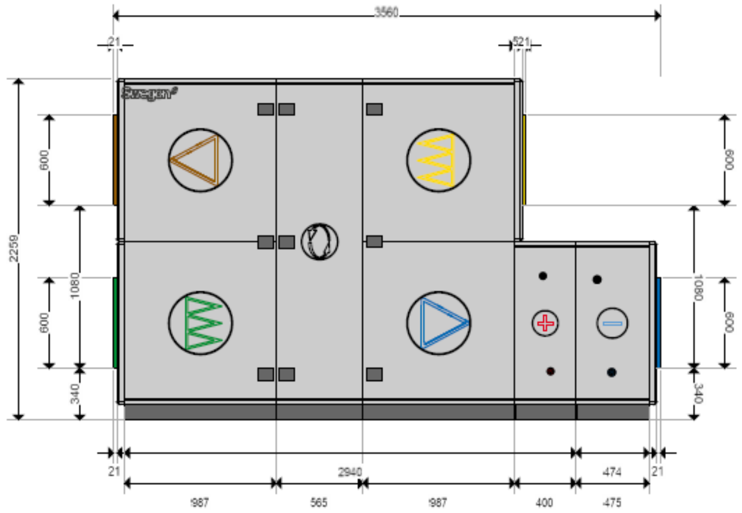
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407775

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 3 - AHU 1		
Unit size		035	
Air density		1.200	kg/m³
Supply air flow		3.000	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	200	Pa
Extract air flow		3.000	m³/s
Static pressure drop	Extract air duct	200	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.77	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.90	kW/(m³/s)
Dry temperature efficiency of supply air, winter		81.6	%
Eurovent Energy Efficiency Class	Summer: A+ ⊆ 2020	Winter: A+	2016
Eurovent; Fs_Pref:	Summer: 0.93	Winter:	0.93
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	035	
Unit weight	1,461	kg
Duct Component Weight	0	kg
Length, max	3,560	mm
Height, max	2,259	mm
Width, max	1,990	mm

Connection size		
outdoor air	1,400 x 600	mm
supply air	1,400 x 600	mm
extract air	1,400 x 600	mm
exhaust air	1,400 x 600	mm

Project: Master
Unit name: Case 3 - AHU 1
Unit ID: AD-10001407775
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 3 AHU 3.2 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 3 - AHU 1 - Design data

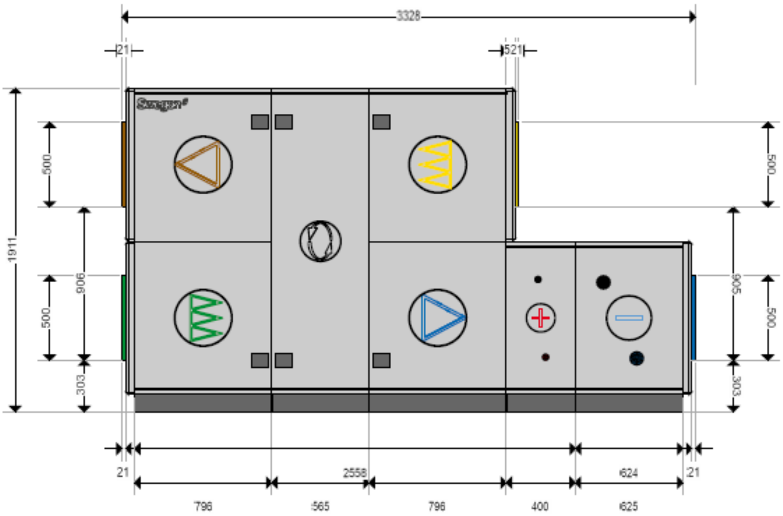
Date: 31/03/2023
32 / 1.0.20230309.1093814
Unit ID: AD-10001407775

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 3 - AHU 1		
Unit size		030	
Air density		1.200	kg/m³
Supply air flow		3.000	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	200	Pa
Extract air flow		3.000	m³/s
Static pressure drop	Extract air duct	200	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	2.95	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	3.21	kW/(m³/s)
Dry temperature efficiency of supply air, winter		78.2	%
Eurovent Energy Efficiency Class	Summer: C C 2020	Winter: C	2016
Eurovent; Fs_Pref:	Summer: 0.86	Winter:	0.86
ErP Commission Regulation (EU) No 1253/2014		Not Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	030	
Unit weight	1,145	kg
Duct Component Weight	0	kg
Length, max	3,328	mm
Height, max	1,911	mm
Width, max	1,600	mm

Connection size		
outdoor air	1,200 x 500	mm
supply air	1,200 x 500	mm
extract air	1,200 x 500	mm
exhaust air	1,200 x 500	mm

Project: Master
Unit name: Case 3 - AHU 1
Unit ID: AD-10001407775
32 / 1.0.20230309.1093814
Date: 31/03/2023

Outdoor air
Supply air
Extract air
Exhaust air

Case 3 AHU 3.3 – Parts of Technical specification from AHU design tool [44]

AHU Design
Technical specification

Swegon

Project: Master
Unit name: Case 3 - AHU 1 - Design data

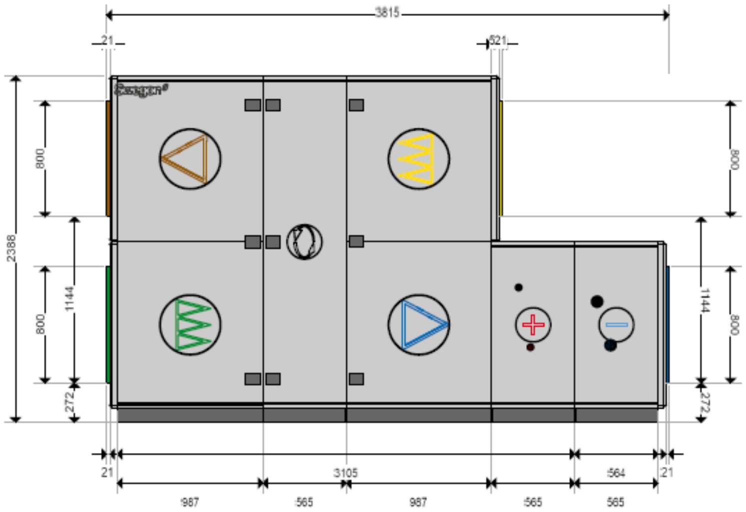
Date: 28/04/2023
32 / 1.0.20230405.1122830
Unit ID: AD-1000140775

GOLD F RX
Manufactured by Swegon, Kvänum, Sweden

Dimensioning data	Case 3 - AHU 1		
Unit size		050	
Air density		1.200	kg/m³
Supply air flow		3.000	m³/s
Static pressure drop	Outdoor air duct	50	Pa
	Supply air duct	200	Pa
Extract air flow		3.000	m³/s
Static pressure drop	Extract air duct	200	Pa
	Exhaust air duct	50	Pa
Climate data		Oslo,	Norway
Weather station, reference		OSLO GARDEMOEN,	Norway
Design outdoor temperature, summer		23.7	°C
Design outdoor humidity, summer		54	%
Design outdoor temperature, winter		-18.4	°C
Design outdoor humidity, winter		97	%
Supply air temperature, summer		17.0	°C
Supply air temperature, winter		20.0	°C
Annual operating period		8760	h

Key Performance Data			
Specific fan power SFPv	With clean filter and including effect of OACF & EATR	1.37	kW/(m³/s)
Specific fan power SFPe	With semi-clean filter and including effect of OACF & EATR	1.50	kW/(m³/s)
Dry temperature efficiency of supply air, winter		83.3	%
Eurovent Energy Efficiency Class	Summer: A+ C 2020	Winter: A+	2016
Eurovent; Fs_Pref:	Summer: 0.71	Winter:	0.71
ErP Commission Regulation (EU) No 1253/2014		Compliant	2018

AHU Design
Sketch: Inspection side



GOLD F RX		
Unit size	050	
Unit weight	1,796	kg
Duct Component Weight	0	kg
Length, max	3,815	mm
Height, max	2,388	mm
Width, max	2,318	mm

Connection size		
outdoor air	1,600 x 800	mm
supply air	1,600 x 800	mm
extract air	1,600 x 800	mm
exhaust air	1,600 x 800	mm

Project: Master
Unit name: Case 3 - AHU 1
Unit ID: AD-1001407775
32 / 1.0.20230405.1122830
Date: 28/04/2023

Outdoor air
Supply air
Extract air
Exhaust air

F - Calculation of floor area for AHU

Calculation of floor area for AHU plant room with Byggforskserien Planløsning 379.310 – *Plassbehov og plassering av tekniske rom for ventilasjonsanlegg* [46]

$$Length_{room} = Length_{AHU} * 2{,}0 \quad [m] \quad (6)$$

$$Width_{room} = Width_{AHU} * 2{,}5 \quad [m] \quad (7)$$

$$Height_{room} = Height_{AHU} * 1{,}2 \quad [m] \quad (8)$$

Table 36. Calculation of floor area for AHU plant room.

		AHU 1.1	AHU 1.2	AHU 1.3	AHU 2.1	AHU 2.2	AHU 2.3	AHU 3.1	AHU 3.2	AHU 3.3
B AHU	**[mm]**	3340	3440	3340	3340	2637	3340	1990	1600	2318
L AHU	**[mm]**	4796	4796	4796	4796	4285	4796	3560	3328	3815
H AHU										
B Room	**[mm]**	8350	8600	8350	8350	6592,5	8350	4975	4000	5795
L room	**[mm]**	9592	9592	9592	9592	8570	9592	7120	6656	7630
H room										
Floor area	**[m2]**	80	82	80	80	56	80	35	27	44

G - Delivered Energy Reports

Case 1 – AHU 1.1 Delivered Energy Report from IDA ICE

SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m^2
Customer		Model volume	16840.2 m^3
Created by		Model ground area	1651.0 m^2
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m^2
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 1-rev02	Average U-value	0.2163 W/(m^2 K)
Simulated	28.04.2023 10:35:23	Envelope area per Volume	0.3056 m^2/m^3

Building Comfort Reference

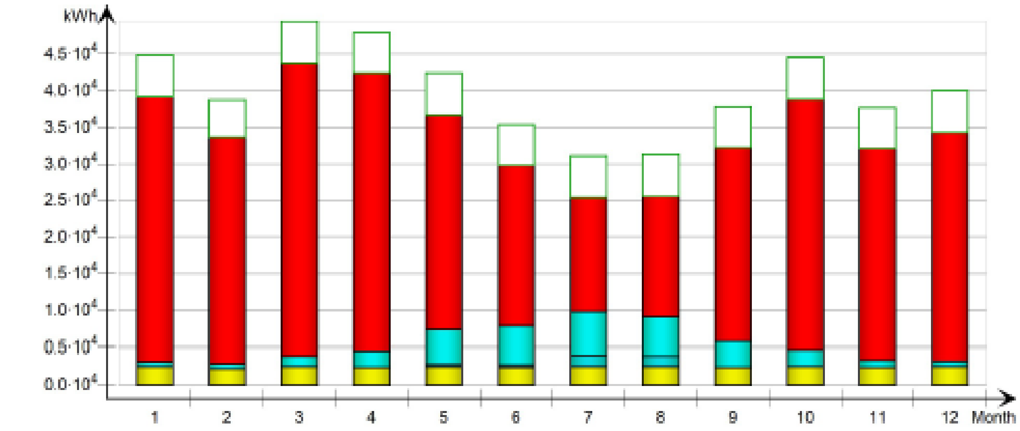
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	29058	5.9	8.25
Electric cooling	3446	0.7	36.47
HVAC aux	320	0.1	0.32
Fan	32718	6.6	14.82
Total, Facility electric	65542	13.2	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	348312	70.3	143.4
Total, Facility district	348312	70.3	
Total	413854	83.6	
Equipment, tenant	67551	13.6	19.17
Total, Tenant electric	67551	13.6	
Grand total	481405	97.2	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	26.8	616.2	0.0	36082.0	5731.0
2	2228.0	0.1	23.0	650.3	0.0	30797.0	5180.0
3	2468.0	0.1	29.7	1422.0	0.0	39842.0	5737.0
4	2389.0	0.1	28.4	2172.0	0.0	37815.0	5555.0
5	2469.0	247.6	28.1	4606.0	0.0	29335.0	5739.0
6	2389.0	264.2	25.1	5158.0	0.0	21903.0	5554.0
7	2469.0	1515.0	33.2	5780.0	0.0	15608.0	5739.0
8	2470.0	1419.0	31.4	5136.0	0.0	16419.0	5742.0
9	2390.0	0.1	23.3	3342.0	0.0	26471.0	5555.0
10	2468.0	0.1	25.9	2258.0	0.0	34090.0	5738.0
11	2387.0	0.1	21.8	915.2	0.0	28819.0	5549.0
12	2466.0	0.1	23.4	661.9	0.0	31131.0	5732.0
Total	29058.0	3446.5	320.1	32717.6	0.0	348312.0	67551.0

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Case 1 – AHU 1.2 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		Building	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 1-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 10:43:29	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

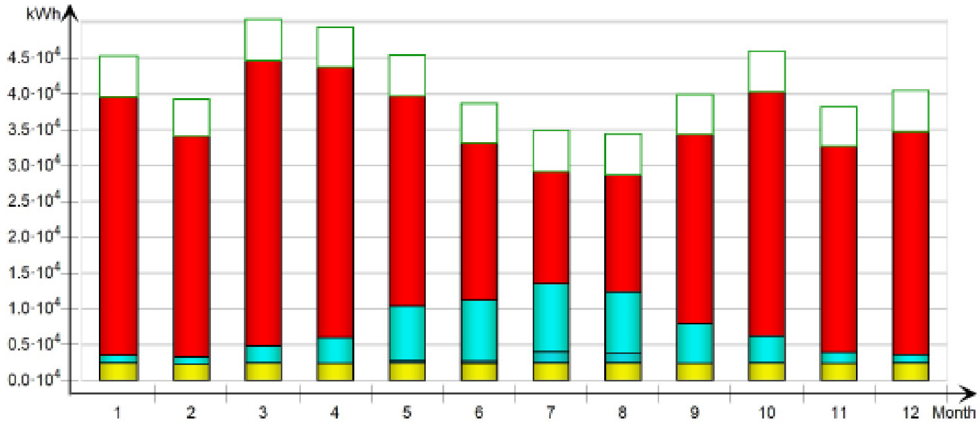
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	29058	5.9	8.25
Electric cooling	3446	0.7	36.47
HVAC aux	320	0.1	0.32
Fan	54037	10.9	24.47
Total, Facility electric	86861	17.5	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	348312	70.3	143.4
Total, Facility district	348312	70.3	
Total	435173	87.9	
Equipment, tenant	67551	13.6	19.17
Total, Tenant electric	67551	13.6	
Grand total	502724	101.5	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Fan (kWh)	Domestic hot water (kWh)	District heating (kWh)	Equipment, tenant (kWh)
1	2465.0	0.1	26.8	1018.0	0.0	36082.0	5731.0
2	2228.0	0.1	23.0	1074.0	0.0	30797.0	5180.0
3	2468.0	0.1	29.7	2348.0	0.0	39842.0	5737.0
4	2389.0	0.1	28.4	3587.0	0.0	37815.0	5555.0
5	2469.0	247.6	28.1	7607.0	0.0	29335.0	5739.0
6	2389.0	264.2	25.1	8519.0	0.0	21903.0	5554.0
7	2469.0	1515.0	33.2	9546.0	0.0	15608.0	5739.0
8	2470.0	1419.0	31.4	8483.0	0.0	16419.0	5742.0
9	2390.0	0.1	23.3	5520.0	0.0	26471.0	5555.0
10	2468.0	0.1	25.9	3730.0	0.0	34090.0	5738.0
11	2387.0	0.1	21.8	1512.0	0.0	28819.0	5549.0
12	2466.0	0.1	23.4	1093.0	0.0	31131.0	5732.0
Total	29058.0	3446.5	320.1	54037.0	0.0	348312.0	67551.0

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Case 1 – AHU 1.3 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		**Building**	
		Model floor area	4953.0 m^2
Customer		Model volume	16840.2 m^3
Created by		Model ground area	1651.0 m^2
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m^2
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 1-rev02	Average U-value	0.2163 W/(m^2 K)
Simulated	28.04.2023 12:17:23	Envelope area per Volume	0.3056 m^2/m^3

Building Comfort Reference

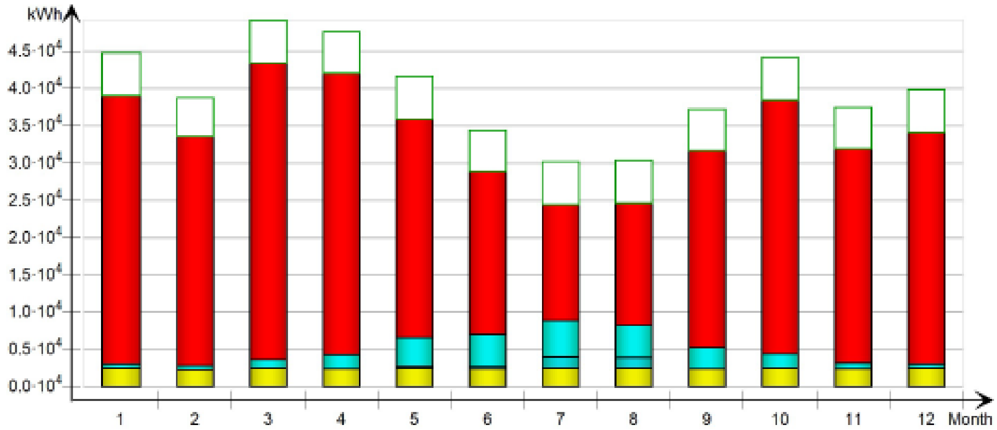
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	**kWh/m^2**	**kW**
Lighting, facility	29058	5.9	8.25
Electric cooling	3446	0.7	36.47
HVAC aux	320	0.1	0.32
Fan	27384	5.5	12.4
Total, Facility electric	60208	12.2	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	348312	70.3	143.4
Total, Facility district	348312	70.3	
Total	408520	82.5	
Equipment, tenant	67551	13.6	19.17
Total, Tenant electric	67551	13.6	
Grand total	476071	96.1	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	26.8	515.8	0.0	36082.0	5731.0
2	2228.0	0.1	23.0	544.4	0.0	30797.0	5180.0
3	2468.0	0.1	29.7	1190.0	0.0	39842.0	5737.0
4	2389.0	0.1	28.4	1818.0	0.0	37815.0	5555.0
5	2469.0	247.6	28.1	3855.0	0.0	29335.0	5739.0
6	2389.0	264.2	25.1	4317.0	0.0	21903.0	5554.0
7	2469.0	1515.0	33.2	4838.0	0.0	15608.0	5739.0
8	2470.0	1419.0	31.4	4299.0	0.0	16419.0	5742.0
9	2390.0	0.1	23.3	2797.0	0.0	26471.0	5555.0
10	2468.0	0.1	25.9	1890.0	0.0	34090.0	5738.0
11	2387.0	0.1	21.8	766.1	0.0	28819.0	5549.0
12	2466.0	0.1	23.4	554.1	0.0	31131.0	5732.0
Total	29058.0	3446.5	320.1	27384.4	0.0	348312.0	67551.0

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Case 2 – AHU 2.1 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 2-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 12:22:22	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

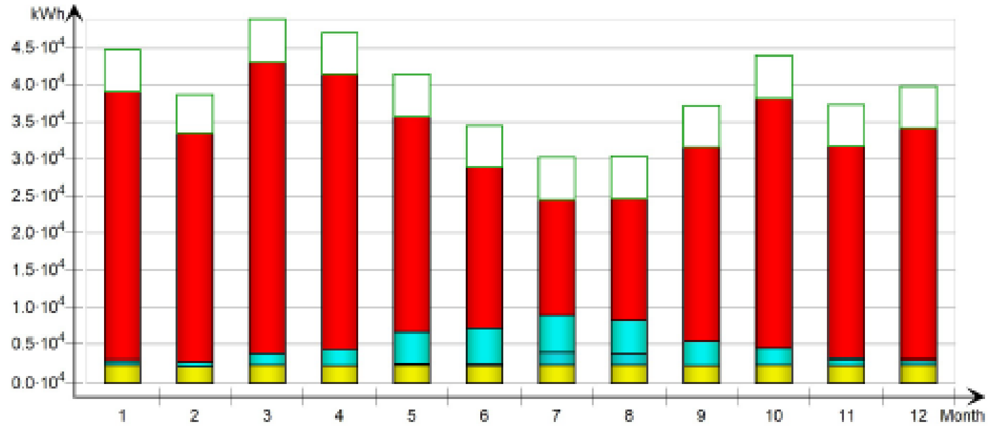
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	**kWh/m²**	**kW**
Lighting, facility	29062	5.9	8.25
Electric cooling	3159	0.6	31.72
HVAC aux	315	0.1	0.27
Fan	28678	5.8	10.86
Total, Facility electric	61214	12.4	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	345818	69.8	137.6
Total, Facility district	345818	69.8	
Total	407032	82.2	
Equipment, tenant	67560	13.6	19.17
Total, Tenant electric	67560	13.6	
Grand total	474592	95.8	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Fan (kWh)	Domestic hot water (kWh)	District heating (kWh)	Equipment, tenant (kWh)
1	2465.0	0.1	26.8	559.2	0.0	36075.0	5730.0
2	2229.0	0.1	22.9	586.3	0.0	30657.0	5181.0
3	2468.0	0.1	29.4	1270.0	0.0	39349.0	5736.0
4	2389.0	0.1	27.9	1923.0	0.0	37190.0	5554.0
5	2470.0	228.3	27.5	4017.0	0.0	29055.0	5741.0
6	2390.0	241.2	24.6	4476.0	0.0	21812.0	5556.0
7	2470.0	1391.0	31.9	4998.0	0.0	15612.0	5743.0
8	2470.0	1298.0	30.2	4460.0	0.0	16427.0	5743.0
9	2390.0	0.1	23.0	2953.0	0.0	26273.0	5556.0
10	2468.0	0.1	25.7	2013.0	0.0	33707.0	5738.0
11	2387.0	0.1	21.6	820.6	0.0	28554.0	5550.0
12	2466.0	0.1	23.4	601.6	0.0	31107.0	5732.0
Total	29062.0	3159.2	314.9	28677.7	0.0	345818.0	67560.0

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Case 2 – AHU 2.2 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m^2
Customer		Model volume	16840.2 m^3
Created by		Model ground area	1651.0 m^2
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m^2
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 2-rev02	Average U-value	0.2163 W/(m^2 K)
Simulated	28.04.2023 12:27:12	Envelope area per Volume	0.3056 m^2/m^3

Building Comfort Reference

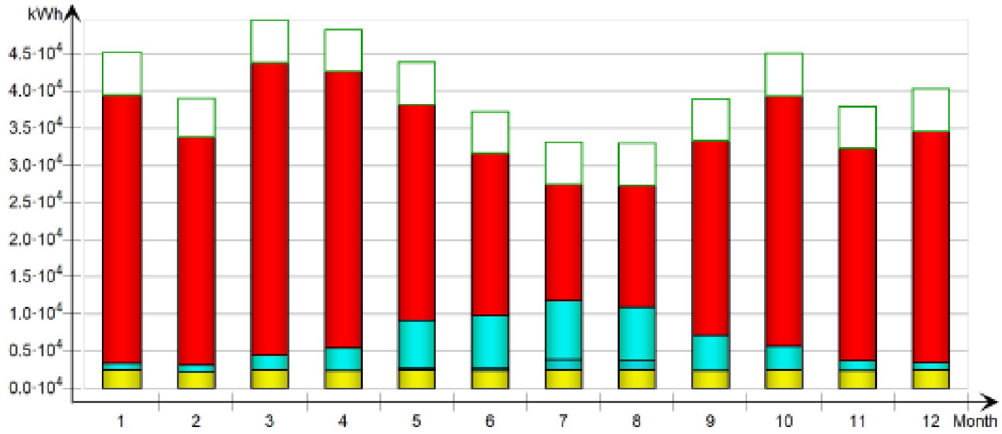
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	29062	5.9	8.25
Electric cooling	3159	0.6	31.72
HVAC aux	315	0.1	0.27
Fan	45503	9.2	17.24
Total, Facility electric	78039	15.8	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	345818	69.8	137.6
Total, Facility district	345818	69.8	
Total	423857	85.6	
Equipment, tenant	67560	13.6	19.17
Total, Tenant electric	67560	13.6	
Grand total	491417	99.2	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	26.8	887.3	0.0	36075.0	5730.0
2	2229.0	0.1	22.9	930.3	0.0	30657.0	5181.0
3	2468.0	0.1	29.4	2016.0	0.0	39349.0	5736.0
4	2389.0	0.1	27.9	3051.0	0.0	37190.0	5554.0
5	2470.0	228.3	27.5	6374.0	0.0	29055.0	5741.0
6	2390.0	241.2	24.6	7102.0	0.0	21812.0	5556.0
7	2470.0	1391.0	31.9	7930.0	0.0	15612.0	5743.0
8	2470.0	1298.0	30.2	7076.0	0.0	16427.0	5743.0
9	2390.0	0.1	23.0	4685.0	0.0	26273.0	5556.0
10	2468.0	0.1	25.7	3195.0	0.0	33707.0	5738.0
11	2387.0	0.1	21.6	1302.0	0.0	28554.0	5550.0
12	2466.0	0.1	23.4	954.5	0.0	31107.0	5732.0
Total	29062.0	3159.2	314.9	45503.1	0.0	345818.0	67560.0

IDA Indoor Climate and Energy
Version: 4.802
License: IDA40:ICE40X:ED170/L2J4C (educational license)

Case 2 – AHU 2.3 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP

Delivered Energy Report

Project		Building	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 2-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 12:31:13	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

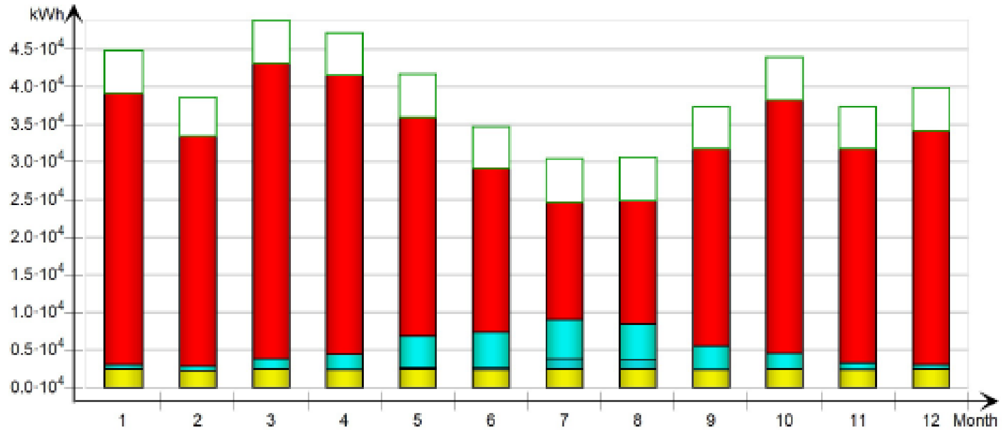
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	29062	5.9	8.25
Electric cooling	3159	0.6	31.72
HVAC aux	315	0.1	0.27
Fan	30018	6.1	11.37
Total, Facility electric	62554	12.6	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	345818	69.8	137.6
Total, Facility district	345818	69.8	
Total	408372	82.5	
Equipment, tenant	67560	13.6	19.17
Total, Tenant electric	67560	13.6	
Grand total	475932	96.1	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	26.8	585.3	0.0	36075.0	5730.0
2	2229.0	0.1	22.9	613.7	0.0	30657.0	5181.0
3	2468.0	0.1	29.4	1330.0	0.0	39349.0	5736.0
4	2389.0	0.1	27.9	2013.0	0.0	37190.0	5554.0
5	2470.0	228.3	27.5	4205.0	0.0	29055.0	5741.0
6	2390.0	241.2	24.6	4685.0	0.0	21812.0	5556.0
7	2470.0	1391.0	31.9	5231.0	0.0	15612.0	5743.0
8	2470.0	1298.0	30.2	4668.0	0.0	16427.0	5743.0
9	2390.0	0.1	23.0	3091.0	0.0	26273.0	5556.0
10	2468.0	0.1	25.7	2107.0	0.0	33707.0	5738.0
11	2387.0	0.1	21.6	858.9	0.0	28554.0	5550.0
12	2466.0	0.1	23.4	629.6	0.0	31107.0	5732.0
Total	29062.0	3159.2	314.9	30017.5	0.0	345818.0	67560.0

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Case 3 – AHU 3.1 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 3-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 12:42:06	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

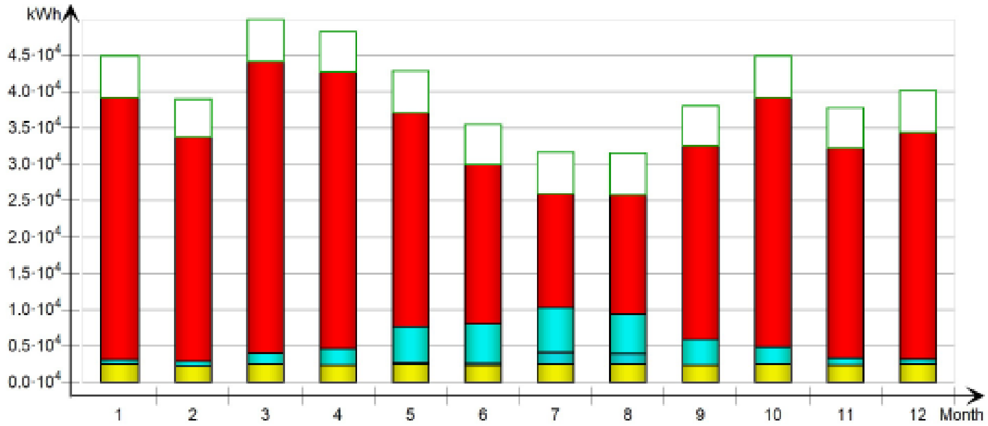
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

		Purchased energy		Peak demand
		kWh	kWh/m²	kW
■	Lighting, facility	29059	5.9	8.25
■	Electric cooling	3556	0.7	38.38
■	HVAC aux	350	0.1	0.33
	Fan	34329	6.9	16.82
	Total, Facility electric	67294	13.6	
■	Domestic hot water	0	0.0	0.0
	Total, Facility fuel*	0	0.0	
■	District heating	349664	70.6	146.6
	Total, Facility district	349664	70.6	
	Total	416958	84.2	
□	Equipment, tenant	67555	13.6	19.17
	Total, Tenant electric	67555	13.6	
	Grand total	484513	97.8	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	29.1	637.1	0.0	36078.0	5731.0
2	2228.0	0.1	25.2	679.5	0.0	30856.0	5180.0
3	2468.0	0.1	32.3	1506.0	0.0	40184.0	5738.0
4	2390.0	0.1	30.8	2275.0	0.0	38067.0	5556.0
5	2469.0	253.5	30.6	4826.0	0.0	29450.0	5739.0
6	2390.0	274.3	27.6	5408.0	0.0	21930.0	5555.0
7	2468.0	1565.0	36.0	6086.0	0.0	15646.0	5738.0
8	2470.0	1463.0	34.1	5387.0	0.0	16405.0	5742.0
9	2389.0	0.1	25.7	3509.0	0.0	26627.0	5555.0
10	2468.0	0.1	28.5	2372.0	0.0	34338.0	5738.0
11	2388.0	0.1	24.1	955.5	0.0	28904.0	5550.0
12	2466.0	0.1	25.8	687.8	0.0	31179.0	5733.0
Total	29059.0	3556.5	349.7	34328.9	0.0	349664.0	67555.0

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Case 3 – AHU 3.2 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 3-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 12:46:41	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

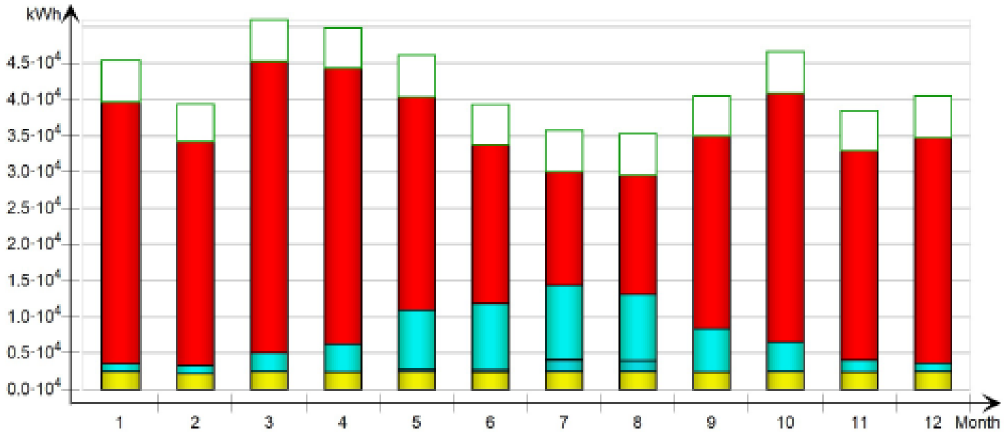
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	29059	5.9	8.25
Electric cooling	3556	0.7	38.38
HVAC aux	350	0.1	0.33
Fan	57989	11.7	28.42
Total, Facility electric	90954	18.4	
Domestic hot water	0	0.0	0.0
Total, Facility fuel*	0	0.0	
District heating	349664	70.6	146.6
Total, Facility district	349664	70.6	
Total	440618	89.0	
Equipment, tenant	67555	13.6	19.17
Total, Tenant electric	67555	13.6	
Grand total	508173	102.6	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	29.1	1076.0	0.0	36078.0	5731.0
2	2228.0	0.1	25.2	1148.0	0.0	30856.0	5180.0
3	2468.0	0.1	32.3	2544.0	0.0	40184.0	5738.0
4	2390.0	0.1	30.8	3844.0	0.0	38067.0	5556.0
5	2469.0	253.5	30.6	8151.0	0.0	29450.0	5739.0
6	2390.0	274.3	27.6	9135.0	0.0	21930.0	5555.0
7	2468.0	1565.0	36.0	10281.0	0.0	15646.0	5738.0
8	2470.0	1463.0	34.1	9100.0	0.0	16405.0	5742.0
9	2389.0	0.1	25.7	5927.0	0.0	26627.0	5555.0
10	2468.0	0.1	28.5	4007.0	0.0	34338.0	5738.0
11	2388.0	0.1	24.1	1614.0	0.0	28904.0	5550.0
12	2466.0	0.1	25.8	1162.0	0.0	31179.0	5733.0
Total	29059.0	3556.5	349.7	57989.0	0.0	349664.0	67555.0

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Case 3 – AHU 3.3 Delivered Energy Report from IDA ICE

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
		Model floor area	4953.0 m²
Customer		Model volume	16840.2 m³
Created by		Model ground area	1651.0 m²
Location	Oslo/Gardermoen_013840 (ASHRAE 2013)	Model envelope area	5146.2 m²
Climate file	NOR_OSLO-GARDERMOEN_013840 (IW2)	Window/Envelope	17.5 %
Case	Case 3-rev02	Average U-value	0.2163 W/(m² K)
Simulated	28.04.2023 12:53:29	Envelope area per Volume	0.3056 m²/m³

Building Comfort Reference

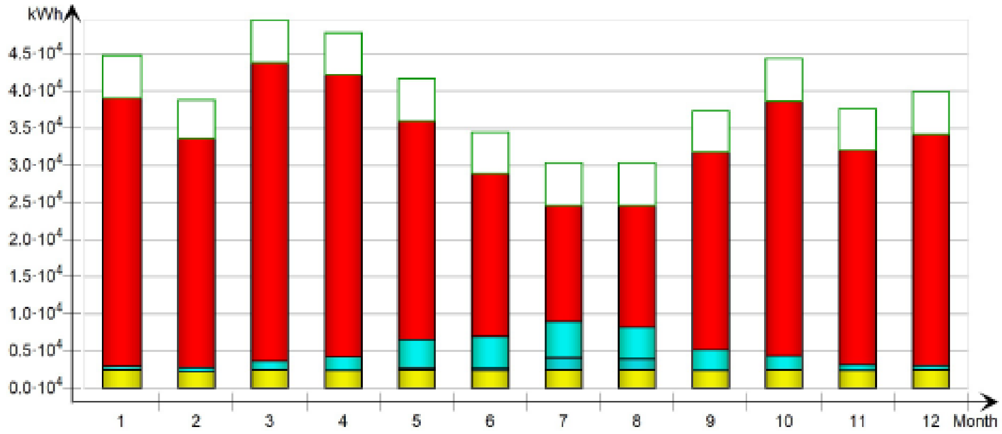
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

Delivered Energy Overview

		Purchased energy		Peak demand
		kWh	**kWh/m²**	**kW**
	Lighting, facility	29059	5.9	8.25
	Electric cooling	3556	0.7	38.38
	HVAC aux	350	0.1	0.33
	Fan	27102	5.5	13.28
	Total, Facility electric	60067	12.1	
	Domestic hot water	0	0.0	0.0
	Total, Facility fuel*	0	0.0	
	District heating	349664	70.6	146.6
	Total, Facility district	349664	70.6	
	Total	409731	82.7	
	Equipment, tenant	67555	13.6	19.17
	Total, Tenant electric	67555	13.6	
	Grand total	477286	96.4	

*heating value

Monthly Purchased/Sold Energy



Month	Facility electric				Facility fuel (heating value)	Facility district	Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fan	Domestic hot water	District heating	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	2465.0	0.1	29.1	503.0	0.0	36078.0	5731.0
2	2228.0	0.1	25.2	536.4	0.0	30856.0	5180.0
3	2468.0	0.1	32.3	1189.0	0.0	40184.0	5738.0
4	2390.0	0.1	30.8	1796.0	0.0	38067.0	5556.0
5	2469.0	253.5	30.6	3810.0	0.0	29450.0	5739.0
6	2390.0	274.3	27.6	4269.0	0.0	21930.0	5555.0
7	2468.0	1565.0	36.0	4805.0	0.0	15646.0	5738.0
8	2470.0	1463.0	34.1	4253.0	0.0	16405.0	5742.0
9	2389.0	0.1	25.7	2770.0	0.0	26627.0	5555.0
10	2468.0	0.1	28.5	1873.0	0.0	34338.0	5738.0
11	2388.0	0.1	24.1	754.4	0.0	28904.0	5550.0
12	2466.0	0.1	25.8	543.0	0.0	31179.0	5733.0
Total	29059.0	3556.5	349.7	27101.8	0.0	349664.0	67555.0

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H - Components and lifetime

Case 1

Table 37. List of included components in case 1 with GWP for A1-A3, B4 and B6 for each component.

A1-A3 [kg CO2-eq]	B4 [kg CO2-eq]	B6 [kg CO2-eq]	Group	Reference S	Re-Instal	Source	Quantity	ID	Type	Dimensjon	Lengde/Anta	Enhet Revit	Lifetime
22568,484	45136,967		365 - AHU		2		1		Gold F RX - 120		4477	kg	20
			365 - AHU									kg	
		409818,96	Energy - NO		60		1				379462	kWh	
		3096409,9	Energy - EU28+NO		60		1				379462	kWh	
		0	Energy - DH		60		1					kWh	
		0	Energy - DC		60		1					kWh	
9652,5	9652,5		362		1		1	NA	Rektangulær kanal	950x1300	50	m	30
85,215	85,215		362		1		1	NA	RIA-1-950x1300	950x1300	2	stk	30
1511,6151	1511,6151		364		1		1	NA	LKK 1300-950-1500	950x1300	4	stk	30
421,6212	421,6212		362		1		1	4291844	LBR	1300x950	2	stk	30
154,0539	154,0539		362		1		1	4293390	LBR	950x1300	1	stk	30
204,32412	204,32412		362		1		1	4293520	LBR	950x1300-5C	2	stk	30
385,50857	1156,5257		364		3		3	4206922	LEO-0-125	125	16	stk	15
674,64	2023,92		364		3		3	4192154	LEO-0-160	160	24	stk	15
1438,9643	4316,8929		364		3		3	4177440	LEO-0-200 VAV	200	43	stk	15
63,36	190,08		364		3		3	4221717	LEO-0-250	250	2	stk	15
44,50446	44,50446		362		1		1	4293579	LEPR	950x1300	1	stk	30
196,56	196,56		364		1		3	4330651	LKR-125-600	125	9	stk	30
505,44	505,44		364		1		3	4307348	LKR-160-600	160	18	stk	30
1347,6	1347,6		364		1		3	4314369	LKR-200-600	200	40	stk	30
84,84	84,84		364		1		3	4340053	LKR-250-600	250	2	stk	30
154,0539	154,0539		362		1		1	4291450	LTTR	950x1300	1	stk	30
210,33	210,33		362		1		3	4140687	magicirc_elbow_full_radius	200	19	stk	30
65,1	65,1		362		1		3	4142731	magicirc_elbow_full_radius	160	10	stk	30
99,54	99,54		362		1		3	4148777	magicirc_elbow_full_radius	125	21	stk	30
8,85	8,85		362		1		3	4154503	magicirc_elbow_full_radius	125	5	stk	30
59,28	59,28		362		1		3	4173667	magicirc_elbow_full_radius	315	2	stk	30
21,72	21,72		362		1		3	4174074	magicirc_elbow_full_radius	250	1	stk	30
56,88	56,88		362		1		3	4176211	magicirc_elbow_full_radius	160	12	stk	30
18,96	18,96		362		1		3	4176227	magicirc_elbow_full_radius	160	8	stk	30
25,2	25,2		362		1		3	4176249	magicirc_elbow_full_radius	160	8	stk	30
32,4	32,4		362		1		3	4243554	magicirc_elbow_full_radius	200	4	stk	30
30,6	30,6		362		1		3	4243590	magicirc_elbow_full_radius	200	5	stk	30
20,7	20,7		362		1		3	4243597	magicirc_elbow_full_radius	200	6	stk	30
102,57	102,57		362		1		3	4245370	magicirc_elbow_full_radius	200	13	stk	30
3,27	3,27		362		1		3	4253759	magicirc_elbow_full_radius	125	1	stk	30
29,22	29,22		362		1		3	4254781	magicirc_elbow_full_radius	400	1	stk	30
33,6	33,6		362		1		3	4254855	magicirc_elbow_full_radius	400	2	stk	30
118,5	118,5		362		1		3	4261112	magicirc_elbow_full_radius	500	2	stk	30
146,16	146,16		362		1		3	4261116	magicirc_elbow_full_radius	500	4	stk	30
2,85	2,85		362		1		3	4261320	magicirc_elbow_full_radius	125	1	stk	30
3,96	3,96		362		1		3	4262124	magicirc_elbow_full_radius	125	2	stk	30
96,78	96,78		362		1		3	4285348	magicirc_elbow_full_radius	500	2	stk	30
26,16	26,16		362		1		3	4289484	magicirc_elbow_full_radius	500	1	stk	30
323,88	323,88		362		1		3	4291252	magicirc_elbow_full_radius	500	4	stk	30
54,18	54,18		362		1		3	4176883	magicirc_reduction_NOR	200-160	21	stk	30
115,56	115,56		362		1		3	4176888	magicirc_reduction_NOR	500-400	6	stk	30
71,1	71,1		362		1		3	4176891	magicirc_reduction_NOR	400-315	6	stk	30
23,76	23,76		362		1		3	4176894	magicirc_reduction_NOR	160-125	12	stk	30
37,95	37,95		362		1		3	4176896	magicirc_reduction_NOR	315-200	5	stk	30
32,04	32,04		362		1		3	4176899	magicirc_reduction_NOR	200-125	12	stk	30
38,52	38,52		362		1		3	4177072	magicirc_reduction_NOR	315-250	6	stk	30
28,98	28,98		362		1		3	4177078	magicirc_reduction_NOR	250-200	7	stk	30
12,93	12,93		362		1		3	4287199	magicirc_reduction_NOR	400-200	1	stk	30
0	0		362		1		1	4293514	magirect_outlet1_001	1300x500	2	stk	30
904,176	904,176		364		1		3	4238258	Orion-ATV-S-T-125+Luna-125-125		23	stk	30
1148,16	1148,16		364		1		3	4241973	Orion-ATV-S-T-160+Luna-160-160		23	stk	30
1377,792	1377,792		364		1		3	4247040	Orion-ATV-S-T-200+Luna-200-200		23	stk	30
353,808	353,808		364		1		3	4153237	Orion-LOV-TA-125+Luna-125-125		9	stk	30
2291,328	2291,328		364		1		3	4134667	Orion-LOV-TA-160+Luna-125-160		54	stk	30
998,4	998,4		364		1		3	4139282	Orion-LOV-TA-160+Luna-160-160		20	stk	30
151,632	151,632		364		1		3	4147350	Orion-LOV-TA-200+Luna-160-200		3	stk	30
179,712	179,712		364		1		3	4151022	Orion-LOV-TA-200+Luna-200-200		3	stk	30
13580,399	13580,399		362		1		1	4291290	Rektangulær kanal	950x1300	70,346535	m	30
384,15065	384,15065		362		1		1	4293507	Rektangulær kanal	500x1300	2,4868948	m	30
1749,8911	1749,8911		362		1		3	4140670	Sirkulær kanal	160	98,363751	m	30
2136,7891	2136,7891		362		1		3	4140681	Sirkulær kanal	315	52,760224	m	30
4268,3707	4268,3707		362		1		3	4141175	Sirkulær kanal	200	160,0439	m	30
2065,4354	2065,4354		362		1		3	4141567	Sirkulær kanal	125	149,34457	m	30
5023,9211	5023,9211		362		1		3	4142223	Sirkulær kanal	500	75,947409	m	30
677,39325	677,39325		362		1		3	4142717	Sirkulær kanal	250	20,79169	m	30
3461,5875	3461,5875		362		1		3	4144006	Sirkulær kanal	400	64,896654	m	30
2952,477	2952,477		362		1		3	4141174	TCPU	0-0	152	stk	30
0	0		362		1		3	4261309	TCPU	1-0	2	stk	30

Case 2

Table 38. List of included components in case 2 with GWP for A1-A3, B4 and B6 for each component.

A1-A3 [kg CO2-eq]	B4 [kg CO2-eq]	B6 [kg CO2-eq]	Group	Reference S	Re-Instal	Source	Quantity	ID	Type	Dimensjon	Lengde/Anta	Enhet Revit	Lifetime
21726,639	0		365 - AHU		0		1		Gold F RX - 100		4310	kg	20
	45136,967		365 - AHU		2		1		Gold F RX - 120		4477	kg	20
		136069,2	Energy - NO		20		1				377970	kWh	
		1028078,4	Energy - EU28+NO		20		1				377970	kWh	
		273212,64	Energy - NO		40		1				379462	kWh	
		2064273,3	Energy - EU28+NO		40		1				379462	kWh	
		0	Energy - DH		60		1					kWh	
		0	Energy - DC		60		1					kWh	
9652,5	9652,5		362		1		1	NA	Rektangulær kanal	950x1300	50	m	30
85,215	85,215		362		1		1	NA	RIA-1-950x1300	950x1300	2	stk	30
1511,6151	1511,6151		364		1		1	NA	LKK 1300-950-1500	950x1300	4	stk	30
421,6212	421,6212		362		1		1	4291844	LBR	1300x950	2	stk	30
154,0539	154,0539		362		1		1	4293390	LBR	950x1300	1	stk	30
204,32412	204,32412		362		1		1	4293520	LBR	950x1300-5(	2	stk	30
385,50857	1156,5257		364		3		3	4206922	LEO-0-125	125	16	stk	15
674,64	2023,92		364		3		3	4192154	LEO-0-160	160	24	stk	15
1438,9643	4316,8929		364		3		3	4177440	LEO-0-200 VAV	200	43	stk	15
63,36	190,08		364		3		3	4221717	LEO-0-250	250	2	stk	15
44,50446	44,50446		362		1		1	4293579	LEPR	950x1300	1	stk	30
196,56	196,56		364		1		3	4330651	LKR-125-600	125	9	stk	30
505,44	505,44		364		1		3	4307348	LKR-160-600	160	18	stk	30
1347,6	1347,6		364		1		3	4314369	LKR-200-600	200	40	stk	30
84,84	84,84		364		1		3	4340053	LKR-250-600	250	2	stk	30
154,0539	154,0539		362		1		1	4291450	LTTR	950x1300	1	stk	30
210,33	210,33		362		1		3	4140687	magicirc_elbow_full_radius	200	19	stk	30
65,1	65,1		362		1		3	4142731	magicirc_elbow_full_radius	160	10	stk	30
99,54	99,54		362		1		3	4148777	magicirc_elbow_full_radius	125	21	stk	30
8,85	8,85		362		1		3	4154503	magicirc_elbow_full_radius	125	5	stk	30
59,28	59,28		362		1		3	4173667	magicirc_elbow_full_radius	315	2	stk	30
21,72	21,72		362		1		3	4174074	magicirc_elbow_full_radius	250	1	stk	30
56,88	56,88		362		1		3	4176211	magicirc_elbow_full_radius	160	12	stk	30
18,96	18,96		362		1		3	4176227	magicirc_elbow_full_radius	160	8	stk	30
25,2	25,2		362		1		3	4176249	magicirc_elbow_full_radius	160	8	stk	30
32,4	32,4		362		1		3	4243554	magicirc_elbow_full_radius	200	4	stk	30
30,6	30,6		362		1		3	4243590	magicirc_elbow_full_radius	200	5	stk	30
20,7	20,7		362		1		3	4243597	magicirc_elbow_full_radius	200	6	stk	30
102,57	102,57		362		1		3	4245370	magicirc_elbow_full_radius	200	13	stk	30
3,27	3,27		362		1		3	4253759	magicirc_elbow_full_radius	125	1	stk	30
29,22	29,22		362		1		3	4254781	magicirc_elbow_full_radius	400	1	stk	30
33,6	33,6		362		1		3	4254855	magicirc_elbow_full_radius	400	2	stk	30
118,5	118,5		362		1		3	4261112	magicirc_elbow_full_radius	500	2	stk	30
146,16	146,16		362		1		3	4261116	magicirc_elbow_full_radius	500	4	stk	30
2,85	2,85		362		1		3	4261320	magicirc_elbow_full_radius	125	1	stk	30
3,96	3,96		362		1		3	4262124	magicirc_elbow_full_radius	125	2	stk	30
96,78	96,78		362		1		3	4285348	magicirc_elbow_full_radius	500	2	stk	30
26,16	26,16		362		1		3	4289484	magicirc_elbow_full_radius	500	1	stk	30
323,88	323,88		362		1		3	4291252	magicirc_elbow_full_radius	500	4	stk	30
54,18	54,18		362		1		3	4176883	magicirc_reduction_NOR	200-160	21	stk	30
115,56	115,56		362		1		3	4176888	magicirc_reduction_NOR	500-400	6	stk	30
71,1	71,1		362		1		3	4176891	magicirc_reduction_NOR	400-315	6	stk	30
23,76	23,76		362		1		3	4176894	magicirc_reduction_NOR	160-125	12	stk	30
37,95	37,95		362		1		3	4176896	magicirc_reduction_NOR	315-200	5	stk	30
32,04	32,04		362		1		3	4176899	magicirc_reduction_NOR	200-125	12	stk	30
38,52	38,52		362		1		3	4177072	magicirc_reduction_NOR	315-250	6	stk	30
28,98	28,98		362		1		3	4177078	magicirc_reduction_NOR	250-200	7	stk	30
12,93	12,93		362		1		3	4287199	magicirc_reduction_NOR	400-200	1	stk	30
0	0		362		1		1	4293514	magirect_outlet1_001	1300x500	2	stk	30
904,176	904,176		364		1		3	4238258	Orion-ATV-S-T-125+Luna-125-125		23	stk	30
1148,16	1148,16		364		1		3	4241973	Orion-ATV-S-T-160+Luna-160-160		23	stk	30
1377,792	1377,792		364		1		3	4247040	Orion-ATV-S-T-200+Luna-200-200		23	stk	30
353,808	353,808		364		1		3	4153237	Orion-LOV-TA-125+Luna-125-125		9	stk	30
2291,328	2291,328		364		1		3	4134667	Orion-LOV-TA-160+Luna-125-160		54	stk	30
998,4	998,4		364		1		3	4139282	Orion-LOV-TA-160+Luna-160-160		20	stk	30
151,632	151,632		364		1		3	4147350	Orion-LOV-TA-200+Luna-160-200		3	stk	30
179,712	179,712		364		1		3	4151022	Orion-LOV-TA-200+Luna-200-200		3	stk	30
13580,399	13580,399		362		1		1	4291290	Rektangulær kanal	950x1300	70,346535	m	30
384,15065	384,15065		362		1		1	4293507	Rektangulær kanal	500x1300	2,4868948	m	30
1749,8911	1749,8911		362		1		3	4140670	Sirkulær kanal	160	98,363751	m	30
2136,7891	2136,7891		362		1		3	4140681	Sirkulær kanal	315	52,760224	m	30
4268,3707	4268,3707		362		1		3	4141175	Sirkulær kanal	200	160,0439	m	30
2065,4354	2065,4354		362		1		3	4141567	Sirkulær kanal	125	149,34457	m	30
5023,9211	5023,9211		362		1		3	4142223	Sirkulær kanal	500	75,947409	m	30
677,39325	677,39325		362		1		3	4142717	Sirkulær kanal	250	20,79169	m	30
3461,5875	3461,5875		362		1		3	4144006	Sirkulær kanal	400	64,896654	m	30
2952,477	2952,477		362		1		3	4141174	TCPU	0-0	152	stk	30
0	0		362		1		3	4261309	TCPU	1-0	2	stk	30

Case 3

Table 39. List of included components in case 3 with GWP for A1-A3, B4 and B6 for each component.

A1-A3 [kg CO2-eq]	B4 [kg CO2-eq]	B6 [kg CO2-eq]	Group	Reference S	Re-Instal	Source	Quantity	ID	Type	Dimensjon	Lengde/Anta	Enhet Revit	Lifetime
27160,82	54321,639		365 - AHU		2		3		Gold F RX - 50		1796	kg	20
			365 - AHU									kg	
		411125,76	Energy - NO		60		1				380672	kWh	
		3106283,5	Energy - EU28+NO		60		1				380672	kWh	
		0	Energy - DH		60		1					kWh	
		0	Energy - DC		60		1					kWh	
3605,4	3605,4		362		1		3	NA	Rektangulær kanal	500x900	10	m	30
93,15	93,15		362		1		3	NA	RIA-1-500x900	500x900	2	stk	30
3266,6258	3266,6258		364		1		3	NA	LKK 900-500-1500	500x900	4	stk	30
140,5404	140,5404		362		1		3	4345366	LBR	500x900	2	stk	30
361,41429	1084,2429		364		3		3	4206922	LEO-0-125	125	15	stk	15
646,53	1939,59		364		3		3	4192154	LEO-0-160	160	23	stk	15
1472,4286	4417,2857		364		3		3	4177440	LEO-0-200 VAV	200	44	stk	15
63,36	190,08		364		3		3	4221717	LEO-0-250	250	2	stk	15
196,56	196,56		364		1		3	4330651	LKR-125-600	125	9	stk	30
505,44	505,44		364		1		3	4307348	LKR-160-600	160	18	stk	30
1347,6	1347,6		364		1		3	4314369	LKR-200-600	200	40	stk	30
84,84	84,84		364		1		3	4340053	LKR-250-600	250	2	stk	30
210,33	210,33		362		1		3	4140687	magicirc_elbow_full_radius	200	19	stk	30
71,61	71,61		362		1		3	4142731	magicirc_elbow_full_radius	160	11	stk	30
113,76	113,76		362		1		3	4148777	magicirc_elbow_full_radius	125	24	stk	30
8,85	8,85		362		1		3	4154503	magicirc_elbow_full_radius	125	5	stk	30
59,28	59,28		362		1		3	4173667	magicirc_elbow_full_radius	315	2	stk	30
21,72	21,72		362		1		3	4174074	magicirc_elbow_full_radius	250	1	stk	30
56,88	56,88		362		1		3	4176211	magicirc_elbow_full_radius	160	12	stk	30
16,59	16,59		362		1		3	4176227	magicirc_elbow_full_radius	160	7	stk	30
22,05	22,05		362		1		3	4176249	magicirc_elbow_full_radius	160	7	stk	30
32,4	32,4		362		1		3	4243554	magicirc_elbow_full_radius	200	4	stk	30
30,6	30,6		362		1		3	4243590	magicirc_elbow_full_radius	200	5	stk	30
20,7	20,7		362		1		3	4243597	magicirc_elbow_full_radius	200	6	stk	30
102,57	102,57		362		1		3	4245370	magicirc_elbow_full_radius	200	13	stk	30
3,27	3,27		362		1		3	4253759	magicirc_elbow_full_radius	125	1	stk	30
29,22	29,22		362		1		3	4254781	magicirc_elbow_full_radius	400	1	stk	30
33,6	33,6		362		1		3	4254855	magicirc_elbow_full_radius	400	2	stk	30
181,68	181,68		362		1		3	4261112	magicirc_elbow_full_radius	630	2	stk	30
110,58	110,58		362		1		3	4261116	magicirc_elbow_full_radius	630	2	stk	30
2,85	2,85		362		1		3	4261320	magicirc_elbow_full_radius	125	1	stk	30
3,96	3,96		362		1		3	4262124	magicirc_elbow_full_radius	125	2	stk	30
147,9	147,9		362		1		3	4285348	magicirc_elbow_full_radius	630	2	stk	30
79,02	79,02		362		1		3	4289484	magicirc_elbow_full_radius	630	2	stk	30
323,88	323,88		362		1		3	4291252	magicirc_elbow_full_radius	500	4	stk	30
73,08	73,08		362		1		3	4292739	magicirc_elbow_full_radius	500	2	stk	30
96,78	96,78		362		1		3	4342939	magicirc_elbow_full_radius	500	2	stk	30
60,54048	60,54048		362		1		3	4345192	magicirc_multi_shape_tran	900x500-500	1	stk	30
60,54048	60,54048		362		1		3	4345729	magicirc_multi_shape_tran	900x500-630	1	stk	30
60,54048	60,54048		362		1		3	4346890	magicirc_multi_shape_tran	800-900x500	1	stk	30
56,76	56,76		362		1		3	4176883	magicirc_reduction_NOR	200-160	22	stk	30
115,56	115,56		362		1		3	4176888	magicirc_reduction_NOR	500-400	6	stk	30
71,1	71,1		362		1		3	4176891	magicirc_reduction_NOR	400-315	6	stk	30
23,76	23,76		362		1		3	4176894	magicirc_reduction_NOR	160-125	12	stk	30
37,95	37,95		362		1		3	4176896	magicirc_reduction_NOR	315-200	5	stk	30
32,04	32,04		362		1		3	4176899	magicirc_reduction_NOR	200-125	12	stk	30
38,52	38,52		362		1		3	4177072	magicirc_reduction_NOR	315-250	6	stk	30
33,12	33,12		362		1		3	4177078	magicirc_reduction_NOR	250-200	8	stk	30
65,37	65,37		362		1		3	4341874	magicirc_reduction_NOR	800-630	1	stk	30
53,1	53,1		362		1		3	4341877	magicirc_reduction_NOR	630-500	2	stk	30
79,2	79,2		362		1		3	4342058	magicirc_reduction_NOR	800-500	1	stk	30
13,53	13,53		362		1		3	4343737	magicirc_reduction_NOR	400-250	1	stk	30
0	0		362		1		3	4346871	magirect_outlet1_001	900x500	1	stk	30
904,176	904,176		364		1		3	4238258	Orion-ATV-S-T-125+Luna-125-125		23	stk	30
1148,16	1148,16		364		1		3	4241973	Orion-ATV-S-T-160+Luna-160-160		23	stk	30
1377,792	1377,792		364		1		3	4247040	Orion-ATV-S-T-200+Luna-200-200		23	stk	30
353,808	353,808		364		1		3	4153237	Orion-LOV-TA-125+Luna-125-125		9	stk	30
2291,328	2291,328		364		1		3	4134667	Orion-LOV-TA-160+Luna-125-160		54	stk	30
998,4	998,4		364		1		3	4139282	Orion-LOV-TA-160+Luna-160-160		20	stk	30
151,632	151,632		364		1		3	4147350	Orion-LOV-TA-200+Luna-160-200		3	stk	30
179,712	179,712		364		1		3	4151022	Orion-LOV-TA-200+Luna-200-200		3	stk	30
4224,257	4224,257		362		1		3	4341818	Rektangulær kanal	500x900	11,716473	m	30
1738,1966	1738,1966		362		1		3	4140670	Sirkulær kanal	160	97,706388	m	30
2136,7891	2136,7891		362		1		3	4140681	Sirkulær kanal	315	52,760224	m	30
4276,042	4276,042		362		1		3	4141175	Sirkulær kanal	200	160,33154	m	30
2063,0857	2063,0857		362		1		3	4141567	Sirkulær kanal	125	149,17467	m	30
2476,2768	2476,2768		362		1		3	4142223	Sirkulær kanal	500	37,434267	m	30
684,67894	684,67894		362		1		3	4142717	Sirkulær kanal	250	21,015314	m	30
3458,8539	3458,8539		362		1		3	4144006	Sirkulær kanal	400	64,845405	m	30
3587,265	3587,265		362		1		3	4159641	Sirkulær kanal	630	29,774776	m	30
246,39462	246,39462		362		1		3	4341827	Sirkulær kanal	800	1,6202711	m	30
3248,685	3248,685		362		1		3	4141174	TCPU	0-0	144	stk	30
0	0		362		1		3	4159640	TCPU	1-0	10	stk	30
0	0		362		1		3	4341826	TCPU	1-1	1	stk	30