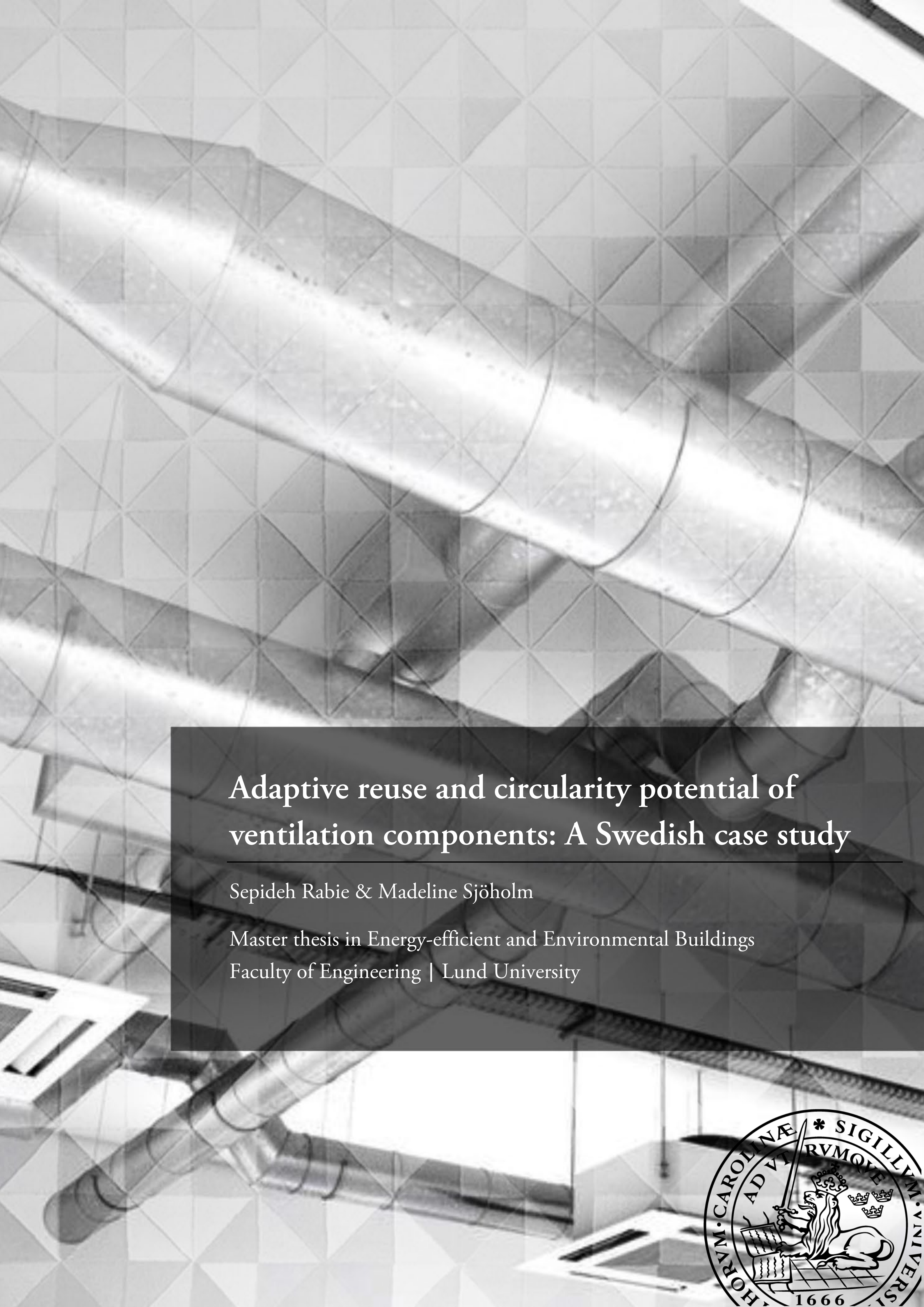

Adaptive reuse and circularity potential of ventilation components: A Swedish case study

Sepideh Rabie & Madeline Sjöholm

Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

Master Programme in Energy-efficient and Environmental Building Design

This international programme provides knowledge, skills and competencies within the area of energy-efficient and environmental building design in cold climates. The goal is to train highly skilled professionals, who will significantly contribute to and influence the design, building or renovation of energy-efficient buildings, taking into consideration the architecture and environment, the inhabitants' behaviour and needs, their health and comfort as well as the overall economy.

The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

To meet 2030 climate goals, industries and governments are adopting circular economy principles to mitigate the building industry's environmental impact through reusing, recovering, and recycling. This report incorporates circularity by examining the adaptive reuse of HVAC components in a case study in Malmö, Sweden. Firstly, the report determined which elements of an HVAC system had the highest potential for reusability through a literature review and interviews with professionals, concluding that air ducts were the most ideal. Secondly, the financial and environmental benefits of reuse were quantified through the Life Cycle Assessment and Life Cycle Costs analysis. The scenarios considered the building's history and future potential to determine what the building owners could have done with the current office’s ventilation design and what the building owners could do in the future if the office were to be transformed into a residential space. In these scenarios, the air ducts available for the office design and air ducts available for future redesign were examined. The results indicated that reusing air ducts can have financial and economic benefits. Still, it is influenced by several factors, such as how many air ducts are available for reuse, if the ducts need to be relocated or if they can remain in their position, if the air ducts need to be stored during the renovation period, and many others. The surveys and interviews demonstrated that government regulators would play a key role in incentivising and guiding building owners and manufacturers in the practice of reuse.

Acknowledgements

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We want to thank the participants who took the time to complete our survey and provided us with their valuable expertise, as well as the interviewees who shared at length their thoughts and experience with the reuse of HVAC components. The topic facilitated fascinating discussions that led to impactful results in this report. Participants in the personal interviews worked at the following companies: Swegon, Lindab, Assemblin, Stena Fastigheter, Systemair AB, Prodikt, Installatörsföretagen, and Boverket.

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I want to express my deepest gratitude to my family for their unwavering support during my academic journey. I also extend my sincere appreciation to Lund University for awarding me the Lund University Global Scholarship, which has provided crucial financial assistance and enabled me to pursue my academic goals. I would also like to thank my partner for being on my side during my education and giving me ongoing support and attention. Lastly, I want to acknowledge my thesis partner, Madeline Sjöholm, for her invaluable support and dedication through this project, making this journey truly memorable.

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I want to thank my family for encouraging me to take on this opportunity to study abroad in Sweden. It was a life-changing experience, which I am deeply grateful for and could not have done without their support. I want to give my partner a special “Thank you!” for empowering me during my endeavours and offering his endless support. Finally, I could not have asked for a better thesis partner. My experience working with Sepideh Rabie has been nothing but enjoyable. Our collaboration worked flawlessly, and I feel very fortunate to have had this experience with her.

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Definitions

Adaptive Reuse: Adaptive reuse refers to restoring or reusing existing buildings' components for another purpose. Instead of demolishing old structures, adaptive reuse intends to give them a new second life by adapting them to meet contemporary needs ("Circular Economy Introduction," n.d.).

Circular Economy: The circular economy is an economic model that prioritises sustainability by reducing waste and increasing efficient resource usage. It replaces the traditional linear model with a closed-loop system where products, materials, and resources are reused, refurbished, remanufactured, and recycled ("Circular Economy Introduction," n.d.).

Life Cycle Cost: Life cycle cost (LCC) is the total expense incurred throughout the entire lifespan of a product or engineering project. It involves considering initial investment cost (IC), operating cost (OC), and discarding cost (DC).

Demolition: Demolition is the process that involves dismantling buildings to save valuable elements for potential reuse (Rathi & Khandve, 2014).

Life Cycle Assessment: Life Cycle Assessment (LCA) is a comprehensive method used to evaluate the environmental impacts of a product, process, or system over its entire life cycle. The life cycle includes all stages, from raw material extraction and production to use, maintenance, and disposal or recycling (Cao, 2017).

Embodied carbon: Embodied carbon refers to the total amount of greenhouse gas emissions, usually measured in carbon dioxide equivalents (CO2e), associated with the entire life cycle of a product, process, or building. This encompasses the emissions produced while extracting raw materials, manufacturing, transportation, construction, use, maintenance, and eventual disposal or recycling (Cao, 2017).

Reference Service Life: Reference Service Life (RSL) is a term used in the field of building and construction to describe the estimated service life of a particular component or system within a structure. It provides a reference point for the expected durability of a specific element in a building (CEN, 2019).

Abbreviations

AD: Adaptive Reuse

AHU: Air Handling Unit

BIM: Building Information Modelling

CE: Circular Economy

GHG: Green House Gas

HVAC: Heating, Ventilation and Cooling

LCA: Life Cycle Assessment

LCC: Life Cycle Cost

MEP: Mechanical and Electrical Plan

RSL: Reference Service Life

1 Introduction

1.1 Background

1.1.1 The Evolving Urban Landscape

The urban landscape undergoes continuous transformation due to ongoing societal and economic changes. Such transformations were observed during the late 1900s when there was a global shift towards deindustrialisation, primarily in North America, Europe, and Asia, leading to the mass decommissioning of industrial spaces (Rowthorn & Ramaswamy, 1997). Presently, a similar trend is evident due to the aftermath of COVID-19. The increased practice of remote work has left office spaces vacant (Quintana Vigiola et al., 2022). According to a study by the Kinsey Global Institute, by 2030, vacant office space could be 20% lower than pre-pandemic times. Among the nine cities investigated – spanning the U.S., U.K., China, Tokyo, Germany, and France – an estimated $800 billion could be at stake due to vacancies (Mischke et al., 2023). Despite the decreased demand for office space, the demand for affordable housing continues to climb. According to the UN-Habitat, the population of cities is expected to increase to three billion by 2030, requiring 96 000 new housing units to be built daily to meet the demand (United Nations, 2022; WGBC, 2023). These examples illustrate the necessary changes to the urban landscape in response to today's challenges and needs.

1.1.2 The impact on the built environment

Constructing these buildings can be costly, both fiscally and environmentally. According to a World Green Building Council (WGBC) report, the built environment contributes approximately 39 % of global CO_2 emissions – 28 % from building operations and 11 % from embodied carbon (Adams et al., 2019). Embodied carbon is the CO_2 emissions from raw material extraction, production, manufacturing, and transportation. Building regulations and government agencies mitigate the impact of buildings by establishing standards for energy use to achieve net-zero energy outputs through renewable energy sources eventually. However, these measures primarily address the operational impact of buildings, often falling short in addressing the emissions from embodied carbon (Adams et al., 2019; Dyson, 2023). The impact of embodied carbon is expected to increase as emissions from building operations are reduced. In 2021, embodied carbon was responsible for 23 % of emissions from the building sector. In 2050, the emissions from embodied carbon are expected to increase to 50 % if building practices continue as they are today (United Nations Environment Programme & Yale Center for Ecosystem + Architecture, 2023). Obsolete buildings can augment the impact of embodied carbon as their lack of functional relevance can result in demolition and subsequent rebuilding. To meet the 2030 climate goals established by the Paris Agreement, scientists and sustainable building advisory groups call on the building industry to reduce embodied carbon emissions by 40 % (Adams et al., 2019). Adaptive reuse can be implemented as a viable solution to address the impending environmental burden of vacant buildings.

1.1.3 Adaptive reuse as a solution

Adaptive reuse, the practice of repurposing existing structures for new functions, contributes to revitalising urban areas and preserving cultural heritage (Hassan, 2023). Though sustainable renovations have served as a critical strategy for minimising environmental impact (De Boeck et al., 2015), adaptive reuse is a relatively new strategy with significant potential. Today's standard adaptive reuse methods include reusing the building's envelope and structure while retrofitting modern HVAC, plumbing, and electrical utilities (Hein & Houck, 2008). Adaptive reuse was widespread in the late 1900s as vacant industrial spaces were renovated for new functions. Notable examples of this include the conversion of an abandoned cement factory in Barcelona into the Taller de Arquitectura headquarters in 1975, the conversion of the Gare d'Orsay station in Paris into Musee d' Orsay in 1986 and the conversion of the Bankside Power Station in London into the Tate Modern Museum in 1995. Vacant industrial spaces are favourable for adaptive reuse as they are designed to bear heavy loads and have open floor plans, making it easier to mould the space for a new function (Cantell, 2005; Hein & Houck, 2008). However, such practices should be implemented in all building types to meet 2030 emission goals.

A recent example of adaptive reuse is a building in The Netherlands. The building stands out as a highly successful circular transformation case, reusing 80 % of materials from the previous structure. Integrating material passport information into the "Madaster Platform" allowed for detailed tracking of repurposed material, exemplifying how practice can be incorporated into other buildings. The success is attributed to a joint venture contract among stakeholders, ensuring a durable, energy-positive building. The building services contractor contributed significantly by implementing digitalised controls and the DLS4 system, enhancing efficiency from design to facilities management and increasing end-of-life recovery opportunities (CE100, 2016).

1.1.4 Adaptive reuse of HVAC components

As previously mentioned, when an existing building is transformed into a new function, the existing HVAC system is discarded and replaced with an entirely new system. However, this conventional practice does not imply that the embodied carbon from HVAC components is negligible. Benachio et al. (2020) conducted an extensive literature review, analysing research on the circular economy and the reuse of materials in the construction industry. Of the 45 articles reviewed, only 18 addressed the reuse of materials and circular economy in project design. No articles addressed the reuse of HVAC components, highlighting the lack of knowledge and consideration. HVAC components are often neglected in life cycle assessments (LCA) analyses regarding embodied carbon as they are too complex for hand calculations. BIM-LCA models can also oversimplify the HVAC system (Kiamili et al., 2020). Kiamili et al. (2020) addressed this challenge by creating a BIM-based LCA model that accounts for geometrical, material, and LCA data using a visual language programming tool. This integration allows for flexibility and customisation, creating a more accurate model. The results showed that the embodied carbon emissions from HVAC systems are approximately 15% - 35 % higher than in previous studies.

Boverket emphasised the need for the building industry to adopt a circular economy mindset to meet the country's climate goals. By 2050, at least 70 % of building material waste must be recycled or reused (Boverket, 2023b). Additionally, as of January 1st, 2022, newly constructed buildings in Sweden must complete a climate declaration to obtain permit approval. The climate declaration must report on the environmental impact, covering stages A1-A5 of the construction stage, A1-A3 of the product stage, and A4-A5 of the construction process stage. The report only accounts for the building's envelope, load-bearing structure, and interior walls (Boverket, 2020a). However, revisions are anticipated in 2027 that may expand the standards for the climate declaration, potentially including building installations (Boverket, 2020a, 2023a).

1.2 Literature Review

The ventilation system was considered the ideal part of the HVAC system for reuse as it takes up the majority of space among all building services and has several related components. A literature review was completed to refute or confirm this notion and to determine which parts of the ventilation system have the highest potential for reusability. The common themes influencing a product's reusability are its life span, durability, adaptability for a new function, and ease of disassembly (Barth & Lindsay McKinnon, 2023).

These factors are highlighted in a report by Bengt Dahlgren (2022), which provided guidelines for reusing building installations. The document focuses on products considered easy to reuse while having significant environmental impact savings. The HVAC-related products included ventilation ducts, space heaters (i.e. radiators), and space coolers (i.e. cooling baffles). Ventilation ducts are simple in design as they are almost entirely made out of galvanised steel and are not electrified. Therefore, the concern for meeting energy efficiency requirements is negligible. Space heaters and coolers have a large environmental impact as they use high amounts of metal, such as steel and copper. These materials can have lifespans of up to 50 years, making them favourable products to reuse. However, because they are often electrified components, upgrades to modern, energy-efficient products may be necessary (Karlsson et al., n.d.).

An ASHRAE Journal article, "Reusing Existing HVAC systems and components", discussed the various scenarios of reusing oversized existing HVAC systems and components. Cases where the minimum building demands are achieved and could reduce energy consumption typically occur when the ductwork is oversized. Theoretically, the pressure drop through the system would be lower than initially anticipated in the design, requiring a lower fan speed and energy savings. Reusing oversized pipes would follow a similar trend as reusing oversized ducts. However, the possible presence of excess air in the pipes would need to be addressed as it could lead to corrosion (Afify, 2015).

1.3 Hypothesis

Upon investigating related research material, it was concluded that the ventilation system's air ducts would be the most practical part of the HVAC system to examine for potential reuse in this case study. This is due to the duct material's longevity, the ductwork design's simplicity, and its capacity for adaptability.

1.4 Aim

This report explores the practical implementation of adaptive reuse of HVAC components, especially air ducts, through a case study in Malmö, Sweden. The investigation seeks to identify any benefits of HVAC reuse, both environmentally and economically. Furthermore, the report aims to uncover how such a practice could be implemented in today's building industry.

The thesis aims to answer the following questions:

1. Which components have the greatest reuse potential?
2. Does the reuse of HVAC equipment have financial benefits?
3. Does the reuse of HVAC equipment have environmental benefits?
4. What are the limitations and barriers to implementing adaptive reuse in the industry?
5. According to the stakeholders, what initiatives must be taken for this practice to succeed?

1.5 Scope

The project begins with interviews and surveys to identify reusable HVAC equipment. The questions were tailored to the respondent's occupation to recognise gaps and barriers from their professional perspectives.

Simultaneously, a case study in Malmö was conducted to see how reuse can be implemented and to identify the fiscal and environmental benefits. This case study examines the history and potential future of an office building's HVAC components, focusing specifically on ventilation. The analysis compares various design scenarios related to the building's past, present, and future: what could have been done, what was done, and what could be done.

The study analyses two types of reuse scenarios. The first is a hypothetical scenario considering reusing air ducts from a decommissioned dance studio on the property for a recently retrofitted office space. This retrospective scenario examines what the building owners could have done differently when designing their new ventilation system. In this case, the ducts are demounted from one location and reinstalled in another.

The second is a prospective scenario, envisioning the transition of the office space into apartments in the future and how the current system can be adapted to meet the air supply needs of residential space, emphasising adaptive reuse. The design incorporates a combination of fixed reuse, keeping air ducts in their current positions, and general reuse, where some ducts are relocated to areas where air supply is required.

The environmental and economic benefits of reuse were determined through computational analysis, employing life cycle cost (LCC) and life cycle assessment (LCA) methodologies. This report does not examine the technical aspect of reuse, such as its effect on the system's performance. Likewise, this report only considers embodied carbon emissions and does not consider emissions from building operations.

2 Method

Figure 1 shows the overall methodology of this project. The research focused on the reusability of HVAC components. Still, to present a thorough analysis, a literature review was completed to hypothesise which parts of an HVAC system had the greatest potential for reuse. Site visits, surveys, and personal interviews were used to confirm or refute the hypothesis.

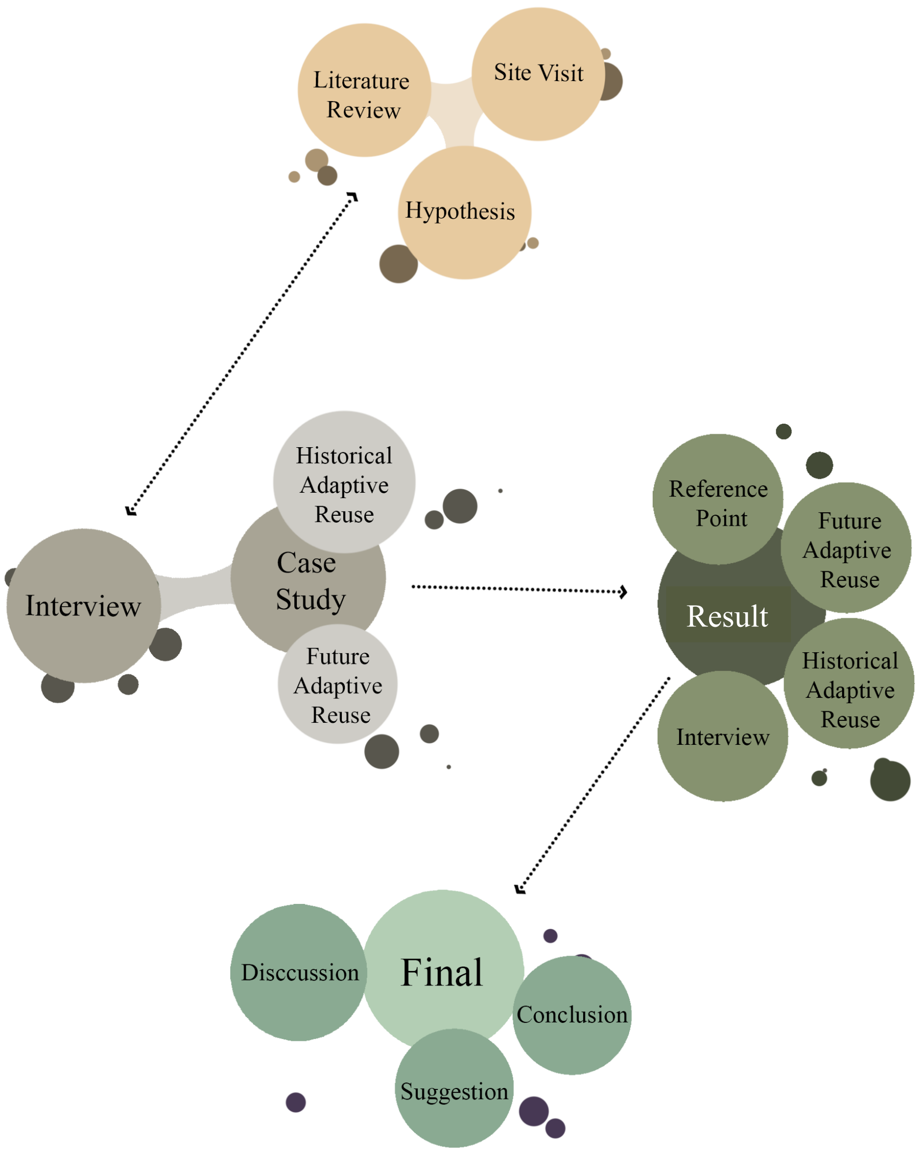

Figure 1. Methodology of project.

2.1 Survey & Interviews

2.1.1 Survey

A Google Form was created to gather insights on how different stakeholders in the building industry perceive the reuse of HVAC components. This included HVAC specialists, architects, sustainability consultants, building developers, and other relevant roles. The form was structured into two sections: the first section featured questions tailored to each participant's specific field, while the second section contained more general questions that all participants answered. This approach aimed to collect specialised insights and perspectives across all professions to see where intersections exist. The survey aimed to identify existing knowledge gaps in the reuse of HVAC components, gauge interest in such practices, and outline necessary steps for adoption within the industry. All questions can be found in the Appendix A.

2.1.2 General Questions

To identify the most influential parties in reusing HVAC components, participants were asked to select which parties would have the greatest role in executing the practice and which framework or infrastructure would be necessary.

The expected barriers to the practice have been divided into four categories: governmental, environmental, technical, and economic. Governmental barriers include a lack of collaboration between different disciplines in the building industry and a lack of guidelines or regulations that would assist in reusing HVAC components. Environmental barriers included potentially using toxic materials commonly found in the components or the neighbouring area. Technical barriers include energy efficiency loss or accessibility to components. Economic barriers include the cost of reusing HVAC components and the influence on the job market.

To discover how participants perceive the reuse of HVAC components, they were asked to select which positive or negative outcome they would expect when implementing this practice. These questions aimed to identify what negative outcomes are expected and then provide recommendations on how to prevent them.

2.1.3 Personal Interviews

Personal interviews were conducted with professionals in HVAC manufacturing and specialists in building regulations. Like in the survey, interviewees were presented with questions specific to their expertise and suitable to all related professions. The personal interviews facilitated in-depth discussions on the reuse of HVAC components and contributed to a better analysis not achievable through the survey alone. All questions and responses can be found in Appendix D.

2.2 Case Study

2.2.1 Description of building & site visit

The industrial heritage building is located in Malmö, Southern Sweden. Originally constructed in the early 1900s as a factory, as shown in Figure 2, it has been converted into numerous functionalities. Today, it operates as a mixed-use building accommodating multiple tenants (Erika Martin Architects AB, 2020). The site's south side, highlighted as Sections A, C, and B in Figure 3, is the main focus of this study and is currently leased by an architecture firm. This part of the building is five storeys and has a heated floor area of 4 825 m^2. The site has five air handling units (AHU) servicing Sections A, B, C, and D. Cooling is provided through the ventilation system, and heating is provided by radiators. The heating source is district heating. The current HVAC system is entirely new and was installed in 2021. A site visit was held to compare what is installed and reflected in the as-built drawings.

Section E of the building is currently a restaurant as of 2014, but from 2003 to 2014, it was a dance studio space. The air ducts from this space were considered for reuse as they were no longer needed when the space was transitioned into a restaurant.

Figure 2. Image of site during the early 1900s. (Photo: Stena Fastigheter, n.d.).

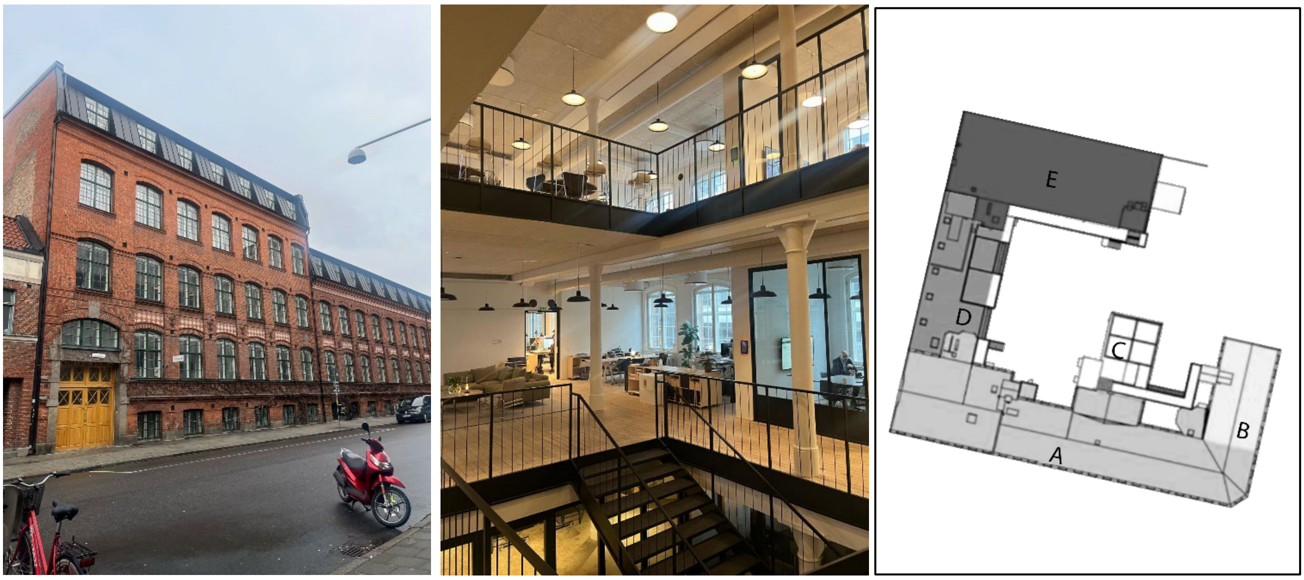

Figure 3. The exterior of the project site (left), current office space (middle), and layout of the property (right). (Left & middle photo: Madeline Sjöholm, 2024) (Right photo: Tyrens, 2020)

2.2.2 Design Scenarios

Two building functions were analysed: office and apartment. **Office Base Case** is the current as-built ventilation design. This system consists of all new materials and systems (e.g. AHUs). **Office Historic Adaptive Reuse** is a design the building owner could have instead utilised if ducts were reused from the decommissioned dance studio. This design combines new and reused materials. This scenario is relevant to mixed-use buildings where HVAC components could be reused from one space to another.

An apartment scenario was analysed next to consider a future building function. **Apartment Base Case** considers a ventilation design with the assumption that the office ventilation system would be removed and replaced with all new material, which is the conventional practice when changing a building's function. **Apartment Future Adaptive Reuse** utilises the existing office ventilation system instead. The adaptive reuse design was done in two scenarios: fixed and fully disassembled. Fixed is the more probable scenario, in which the ducts that can remain in their current positions will stay there. Complete disassembly is a more cautious scenario where the ducts would all be disassembled for cleaning purposes or to complete surrounding renovations.

2.3 Data collection and modelling

2.3.1 Existing office ventilation system

The 3D model, as shown in Figure 4, was provided by the building owner and was drawn using MagiCAD, a plugin for Autodesk Revit, a BIM software. MagiCAD is a tool mechanical engineers use to create 3D designs for HVAC systems. It allows manufacturer-specific products and their associated specifications to be uploaded into a design (MagiCAD Group, 2022). This feature streamlined the LCA and cost analysis process as data, such as weight, length, area, and airflow rates, were accessible. Ventilation plans for each floor were also analysed to understand how the floor plan influenced the duct layout. Refer to Appendix B and Appendix E for design plans and duct specifications.

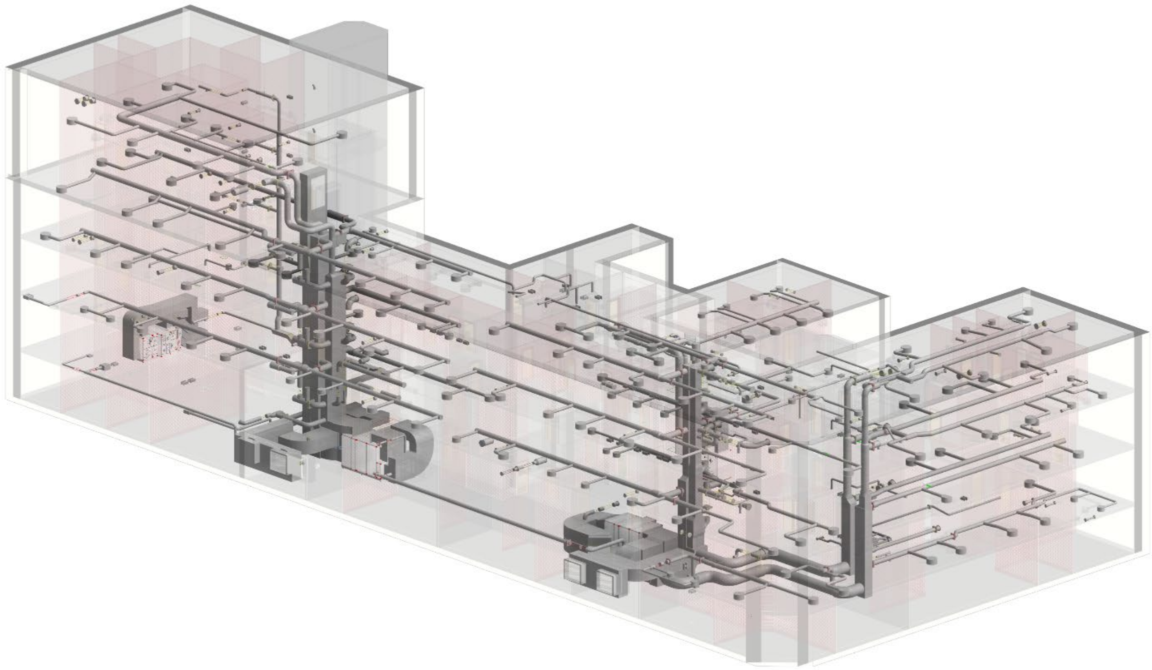

Figure 4. Existing office ventilation system

2.3.2 Dance studio ventilation system

The ventilation design plans from the dance studio were made available through Malmö's City Planning Department's digital archive ("Bilden 10," 2003). Ducts with the same length and diameters as the ducts in the office ventilation design were used in the **Office Historic Adaptive Reuse** scenario. This excluded a visual inspection of the ducts to assess their conditions as the ducts were no longer present in the building. Refer to Appendix F for the dance studio's ventilation design plans.

2.3.3 Future Apartment Ventilation System

In the **Apartment Future Adaptive Reuse** scenario, the office floor plans were transformed into apartments of various sizes. The placement and dimensions of the apartments were influenced by access to daylighting, proximity to staircases, and the location of existing supply air ducts and terminals. Calculations confirmed compliance with residential air flow standards, as stipulated in BBR 29, which requires a minimum airflow of 0.35 l/s per m^2 for occupied spaces (Boverket, 2020b). The provided air flows from the Revit model were used to assess whether the airflow rates of the apartment spaces were within the design capacity. Refer to Appendix G and Appendix F for design plans and air flows.

Given that the airflow requirements for the office space were higher than the required airflows of the apartment spaces, most air ducts were kept in their current position and would not require disassembling and reconfiguring. Few air ducts were reintegrated into the design to ensure adequate air supply in designated areas.

2.4 Life Cycle Assessment (LCA)

2.4.1 Environmental Product Declaration Data

The LCA was completed using the OneClickLCA plugin tool, an automated LCA software containing generic and product-specific data (One Click LCA LTD, 2024). The 3D model was uploaded into OneClickLCA, where the ventilation design equipment was automatically separated into its respective categories: ducts, duct accessories, air terminals, insulation, and mechanical equipment. Within each category, subcategories were then established to break down the components further: supply ducts, exhaust ducts, supply diffusers, exhaust diffusers, duct fittings, silencers, dampers, duct insulation, air handling unit (AHU), etc. Refer to Figure 5 to see how EPDs were prioritised in this study. Generic EPD data from OneClickLCA for Sweden were prioritised to make the results comparable to similar projects. The manufacturer's EPD was used if generic data was unavailable for a product. In cases where neither generic nor manufacturer-specific EPDs were available, EPDs from other manufacturers from within Sweden were used. Using EPDs from Swedish manufacturers was prioritised, as the energy sources for manufacturing, transportation, and construction would be similar.

However, in cases where neither of the previous options was available, EPDs from other regional manufacturers, such as Norway and Finland, were used.

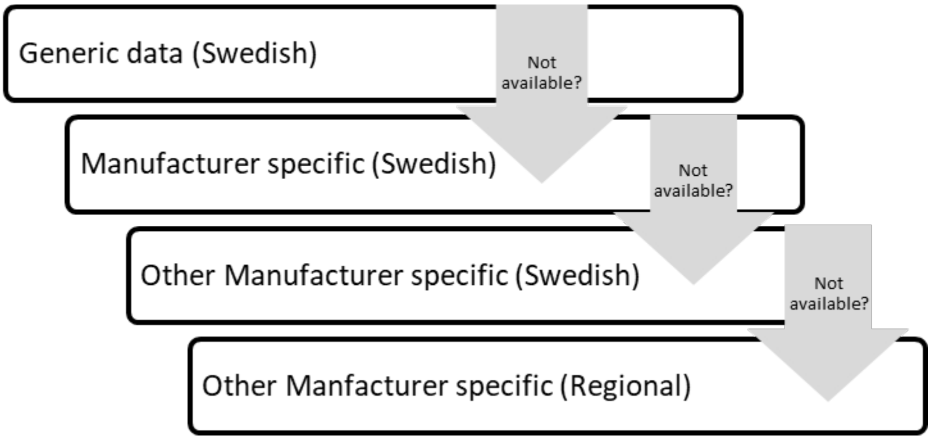

Figure 5. Prioritisation of EPDs used for LCA calculations.

2.4.2 Life cycle stages

The standard SS-EN 15804+A2 (EN 15804, 2019) was used to calculate the LCA in OneClickLCA (CEN, 2019). Figure 6 displays all the stages that are considered in the standard. A1-C4 accounts for embodied carbon emissions, except for stages B6 and B7, which account for operational carbon emissions. Stages A1-A3 account for emissions in the product stage; during these stages, the materials needed to assemble the product are extracted and transported to a facility to be manufactured. Stages A4-A5 account for emissions in the construction phase. The A4 stage is emissions from transporting the product to the construction site, while the A5 stage is emissions from installing the product. The B stages account for emissions from the use phase, and stages B1-B5 include the emissions from using, maintaining, repairing, replacing, and refurbishing the product. The end-of-life stage consists of stages C1-C4, accounting for emissions from deconstructing the product, transporting the product to a waste facility, and the waste process. The D stage is outside of the scope of an LCA but accounts for the benefits of reusing, recovering, or recycling the product (Masson, 2023).

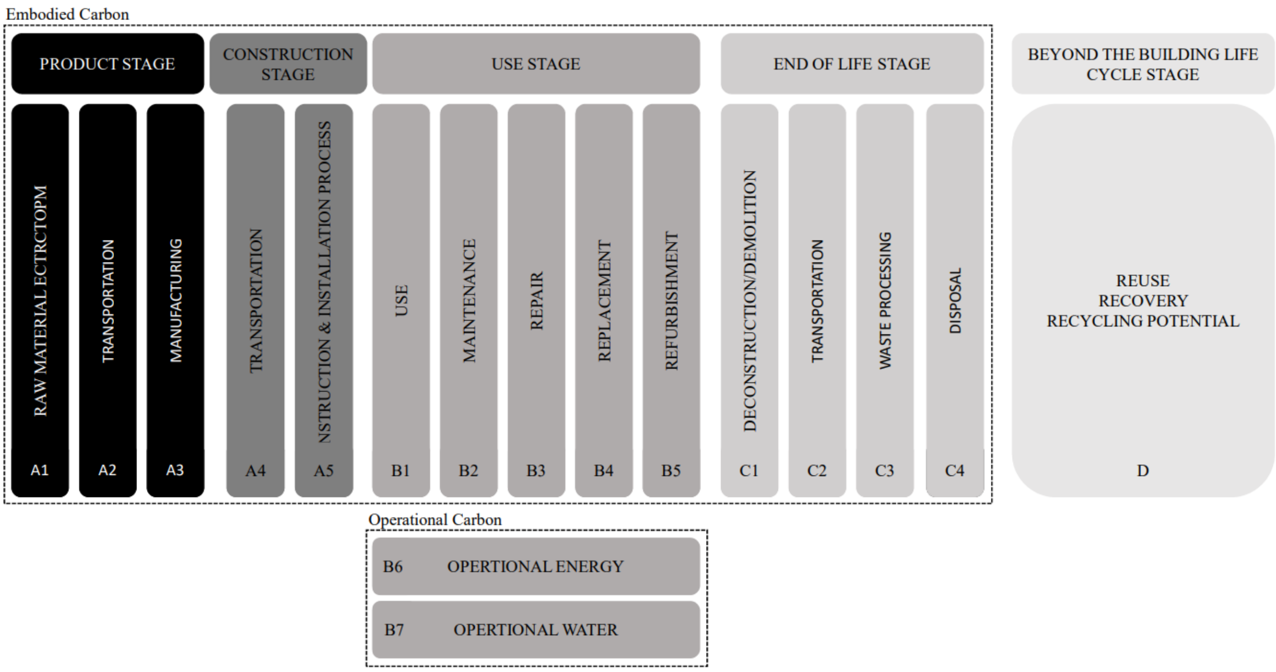

Figure 6. Life cycle stages, adapted from (BNP, Media, 2021)

2.4.3 Environmental Impact Category

The global warming potential (GWP) category, measured in kilograms of CO_2 equivalent, is prioritised in this report as it is the main focus of many government agendas to mitigate the climate crisis. The European

Commission established the European Green Deal to reduce the EU's greenhouse gas emissions by at least 55 % by 2030 (European Commission. Directorate General for Communication., 2023), while Sweden's Climate Act aims to have net zero greenhouse gas emissions by 2045 (Persson et al., 2024).

2.4.4 Life Cycle Assessment of all ventilation components

The LCA aimed to confirm the hypothesis and to identify which ventilation components possess the highest total global warming potential. In this calculation, LCAs of all ventilation components in the building accounted for stages A1- B4 with a calculation period of 50 years. This assumption directly affects the emissions in the B stage as some components have a service life lower than 50 years and would need to be replaced during the calculation period. Please refer to Appendix H for the service life of each component. The transportation distance in all LCA calculations is 110 km, as this was the default value in OneClickLCA. The functional unit in the LCA calculation of this section is one ventilation system in the case study building with a total floor area of 4 825 m^2.

2.4.5 Life cycle assessment of adaptive reuse scenarios

The **Office Base Case** scenario consisted of stages A1-A5, material extraction and manufacturing of new air ducts, and stages C1-C4, disposal of the air ducts from the dance studio. Table 1 displays the mass of the ducts included in each life cycle stage. In the LCA calculation of this section of the study, the functional is the total mass of ducts and fittings in the case study building with a total floor area of 4 825 m^2.

Table 1. Mass of duct in each LCA stage.

Office Base Case			
LCA Stages	**Amount New**	**Amount Reused**	**Amount Discarded**
A1-A5	3 056 kg	-	-
B2	-	0 kg	-
C1-C4	-	-	205 kg

Office Historic Adaptive Reuse was a combination of new material and reused material. Figure 7 shows the LCA stages associated with this scenario. The new material was accounted for in stages A1-A5, while the reused material was accounted for in stages B2. Roughly 175 kg of duct could be reused from the dance studio. In the case of reuse, maintenance consists of disassembling ducts from the dance studio and reinstalling them at the office location. This impact is equivalent to the impact from stage A5 being completed twice. Stages C1-C4 account for the disposal of ducts that could not be reused, consisting of approximately 30 kg of duct material.

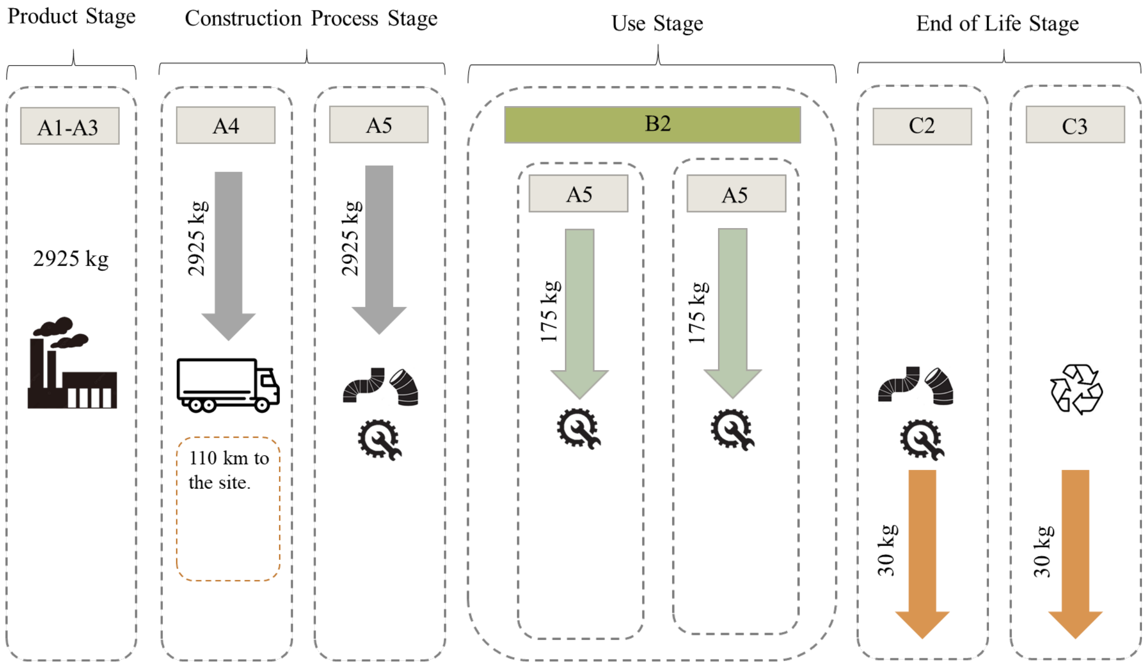

Figure 7. LCA stages for Office Historic Adaptive Reuse scenario.

For the **Apartment Base Case**, it was assumed that the office ventilation would be completely disposed of and replaced with a new ventilation system for an apartment space. Stages A1-A5 account for the impact of new material, while stages C1-C4 account for the disposal of the office ducts. Table 2 displays the mass of the duct that is included in each life cycle stage.

Table 2. Mass of duct in each LCA stage

Apartment Base Case			
LCA Stages	**Amount New**	**Amount Reused**	**Amount Discarded**
A1-A5	2 819 kg	-	-
B2	-	0 kg	-
C1-C4	-	-	3 056 kg

Apartment Future Adaptive Reuse, shown in Figure 8, consisted of stages A1-A5 for new ducts and B2, the impact of reusing the existing ducts. Stages C1-C4 only concerned the disposal of ducts that were available for reuse but were not needed. The ducts that would be hypothetically disposed of when the building had reached the end of its life cycle were not accounted for since it was outside the scope of this study. The final amount of ducts being disposed of at the end of the building's life span would be the same, regardless of whether the ducts were from new material or reused.

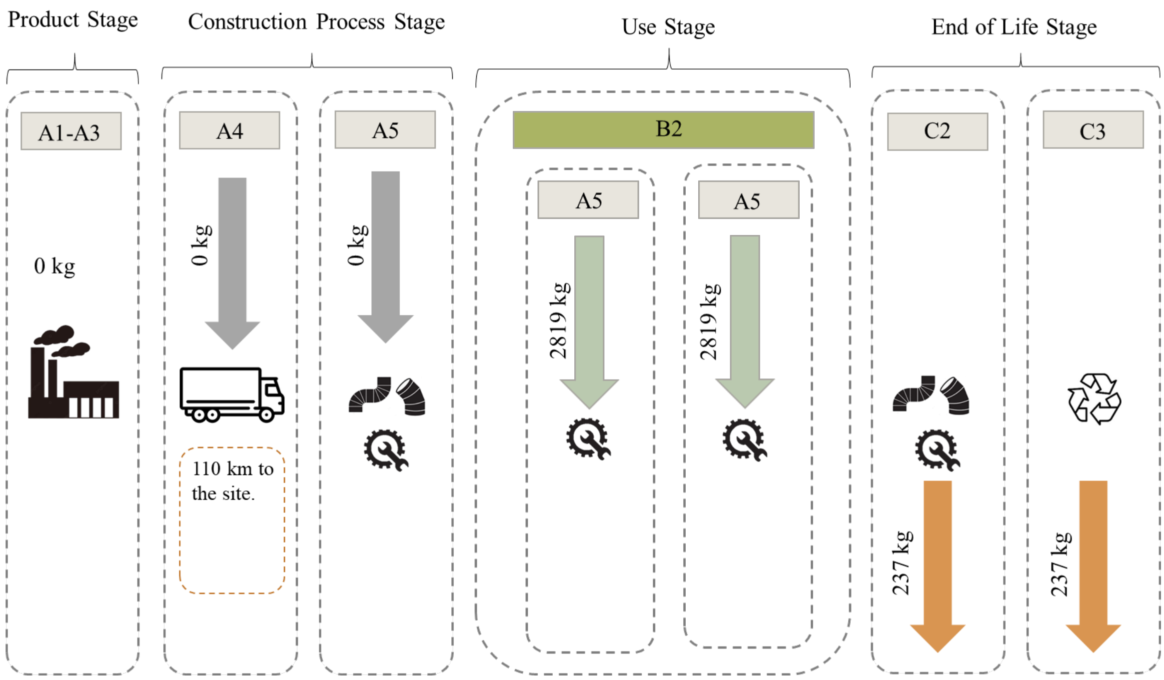

Figure 8. LCA stages for Apartment Future Adaptive Reuse.

For **Office Historic Adaptive Reuse**, the calculation period would be 2014 to 2021. In 2014, the dance studio was decommissioned, making the air ducts available for reuse. From 2014, it was assumed the air ducts were stored onsite until 2021 when the office was retrofitted. For **Apartment Future Adaptive Reuse**, the calculation period for the LCA is the renovation period in the future, which would be in the year 2030, when the office is transformed into a residential space. In all LCA calculations, the embodied carbon emissions were calculated based on the duct mass, as this could account for duct diameter and length.

2.4.6 Global warming potential of different reusing scenarios

A reference point was provided to indicate the expected CO_2 emissions for each stage under various reuse scenarios for 1 kg of a duct. These scenarios included 0 % reuse (100 % new), 10 % reuse (90 % new), 30 % reuse (70 % new), 50 % reuse (50 % new), 70 % reuse (30 % new), 100 % reuse (0 % new). Here, "reuse" refers to the adaptive reuse of ducts (and fittings), while "new" refers to newly purchased ducts (and fittings) to fulfil the building's requirements. This analysis will offer an overview of the environmental impact of adaptive reuse and the anticipated CO_2 emission related to reducing 1 kg of duct under different adaptive reuse scenarios. Providing such a reference point will be a foundation for future studies in this field. The following formula could be used to calculate the GWP in different adaptive reuse scenarios. X% represents the percentage of ducts that will be reused in the new project. Z% indicates the percentage that will be discarded due to building transformations or because the ducts that are not in suitable condition for the new project. Y% represents the amount that needs to be purchased for the new project. Emissions from each stage are found in Appendix H.

Equation 1. Total GWP calculation in different adaptive reuse scenarios

$$\begin{aligned}\textbf{Total GWP} = {} & \text{Total mass of ducts in base case} \times \text{X\%} \times \text{emissions from stage B2} \\ & + \text{Total mass of ducts in base case} \times \text{Z\%} \times \text{emissions from stage C1} - \text{C4} \\ & + \text{Total mass of new ducts} \times \text{Y\%} \times (\text{emission from stage A1} - \text{A5})\end{aligned} \tag{1}$$

2.5 Life cost assessment (LCC)

A life cycle cost assessment was completed for each design scenario. This included the material and labour cost for installation and disassembling, which depended on the duct length. Material and labour costs for the different duct diameters and lengths were collected from Wiksell Sektionsfakta. These values can be found in Appendix B and do not include the value-added tax (VAT) (Wiksell Sektionsfakta, 2024).

2.5.1 Estimated cost of storage

The storage cost was estimated by contacting a storage facility for a quote. A rate of 12 SEK per m^2 per month was applied to the storage calculations. The total area of the ducts was roughly 210 m^2, and it was assumed the needed storage time would be a maximum of two years. Inflation was also considered because the adaptive reuse project would take place in 2030. Sweden's target inflation is 2 % (Riksbank, 2024); however, recent inflation over the years has shown volatility (O'Neil, 2024). Therefore, a range of 3 % to 7 % was considered to evaluate how various economic conditions might impact costs: 2 % (14 SEK per m^2 per month), 3 % (15 SEK per m^2 per month), 5 % (19 SEK per m^2 per month), and 7 % (22 SEK per m^2 per month).

2.5.2 LCC Reference point for future studies

This section provides information to support future studies. It demonstrates the estimated cost of reusing 1 m of the duct for various diameters. This calculation includes the storage, dismantling, and installation costs provided in Appendix B. However, transportation and cleaning inspection costs are not included in this section. It is assumed that this section aims to establish a benchmark for future studies, and the storage location may vary for each case study.

2.6 Use of Generative Artificial Intelligence

Chat GPT was used as a language editor to correct grammar and word usage. The tool was not used to generate text, gather information related to the topic or perform calculations.

2.7 Assumptions & Limitations

Various assumptions were made for this analysis due to limitations and lack of accessible information. For instance, it was assumed that commercial storage was unnecessary for this case study since the site was concerned about having enough space to store the existing ducts during renovations. Therefore, the LCC and LCA analysis did not include the cost and environmental impact of storage and transportation to and from a storage facility. Additionally, the costs and environmental impacts from cleaning and testing for reusability were not included in the LCC and LCA analysis as data on the matter is limited. It was assumed that the cost, fiscally and environmentally, of uninstalling the air ducts would be equal to installing the air ducts as the same level of care and labour is expected.

It was assumed that if an existing duct had the exact diameter and length needed for a design, it could be reused. This assumed that the ducts were in acceptable condition for reuse, avoiding performance uncertainty due to rust or physical damage. Furthermore, it was assumed that reusing ducts requires the same maintenance as new ducts and, therefore, was not included in the LCC and LCA. In this project, "duct" also includes fittings, such as tees and elbows.

Because the office's airflows were higher than those needed for the apartment, it was concluded that the existing office ventilation design was oversized for the apartment and that there would not be a loss of efficiency or need for a new AHU (Afify, 2015).

3 Results

3.1 Survey

The survey was completed by 32 participants from various countries and industries, as shown in Figure 9. HVAC-related professions included HVAC manufacturers and HVAC/mechanical engineers. Those categorised as “Others” comprised individuals involved in project management, structural engineering, energy engineering, design management, project development management, construction, or building regulators.

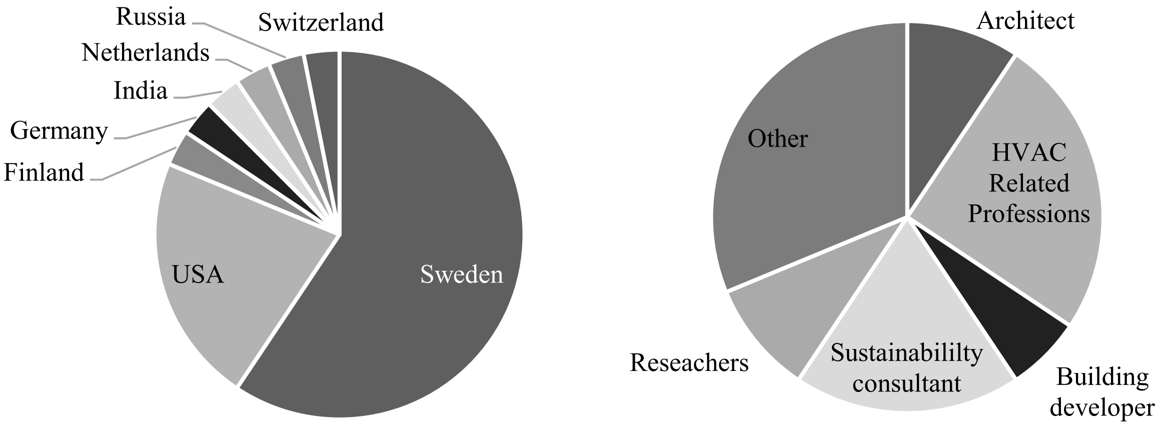

Figure 9. Location of employment (left) and job position of participants (right).

According to Figure 10, 20 out of 32 participants selected HVAC/mechanical engineers as the party they felt they would rely on the most to execute the reuse of HVAC components. 5 out of the 6 HVAC/mechanical engineers who completed this survey agreed that this position would be influential. The manufacturers and sustainability consultants voted unanimously for this option as well. The second most impactful party was HVAC manufacturers, with 18 out of 32 votes. The participating manufacturers and building owners agreed that manufacturers would play a key role in reusing HVAC components. Project managers also saw HVAC installers as important, and building owners mainly relied on sustainability consultants. HVAC/mechanical engineers heavily relied on government regulators.

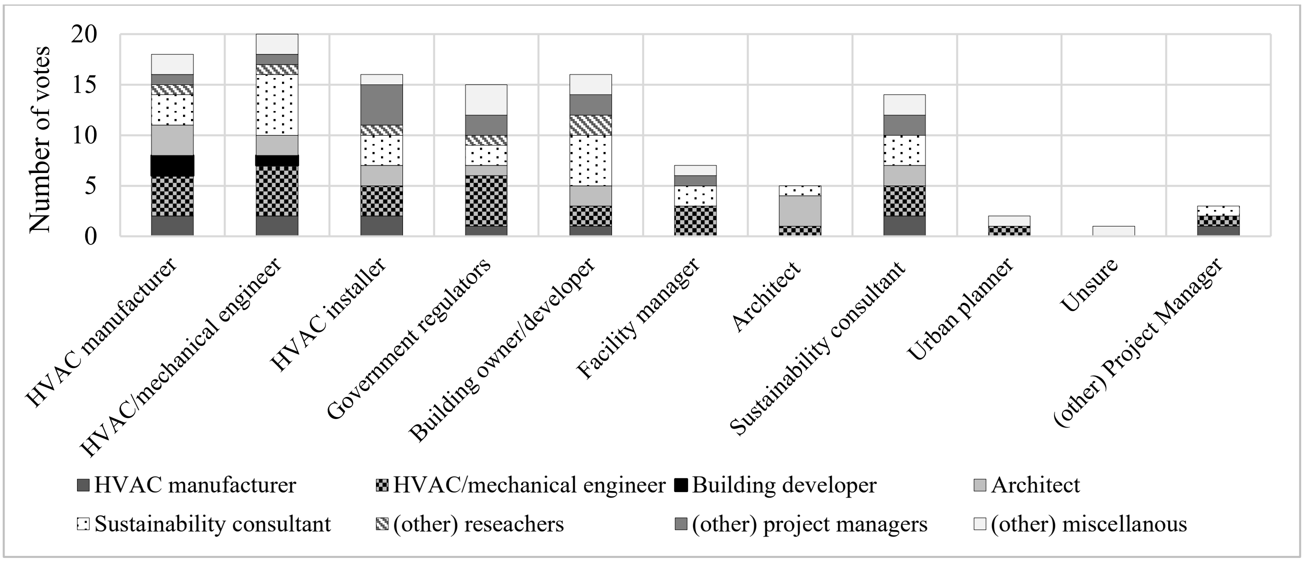

Figure 10. Which parties would have the greatest role in executing the reuse of HVAC components?

When participants were asked which infrastructure they felt was needed to implement reuse, 19 out of 32 identified storage facilities and regulations as the most critical areas, as seen in Figure 11. The need for market demand closely followed this. Sustainability consultants did not consider the need for material passports and EPDs important.

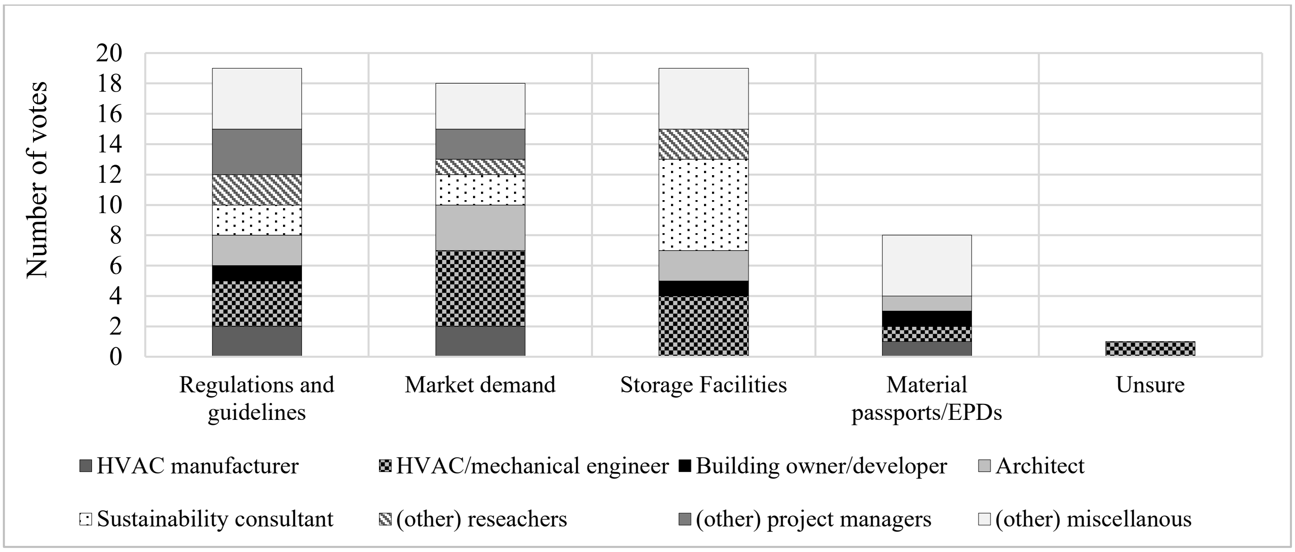

Figure 11. What framework or infrastructure do you need to start the practice of reuse?

As shown in Figure 12, 22 of 32 participants expected reduced material usage when asked what outcome was expected when reusing HVAC components. In turn, 21 respondents noted that material reuse can lead to a reduction in embodied carbon emissions. The third and fourth highest-voted categories were decreased material costs and increased installation costs due to the increased diligence and craftsmanship required for dismantling used products. Finally, increased maintenance and reduced energy efficiency options received 12 and 11 votes, respectively. Fewer professionals believed that reusing materials would increase maintenance compared to current practices.

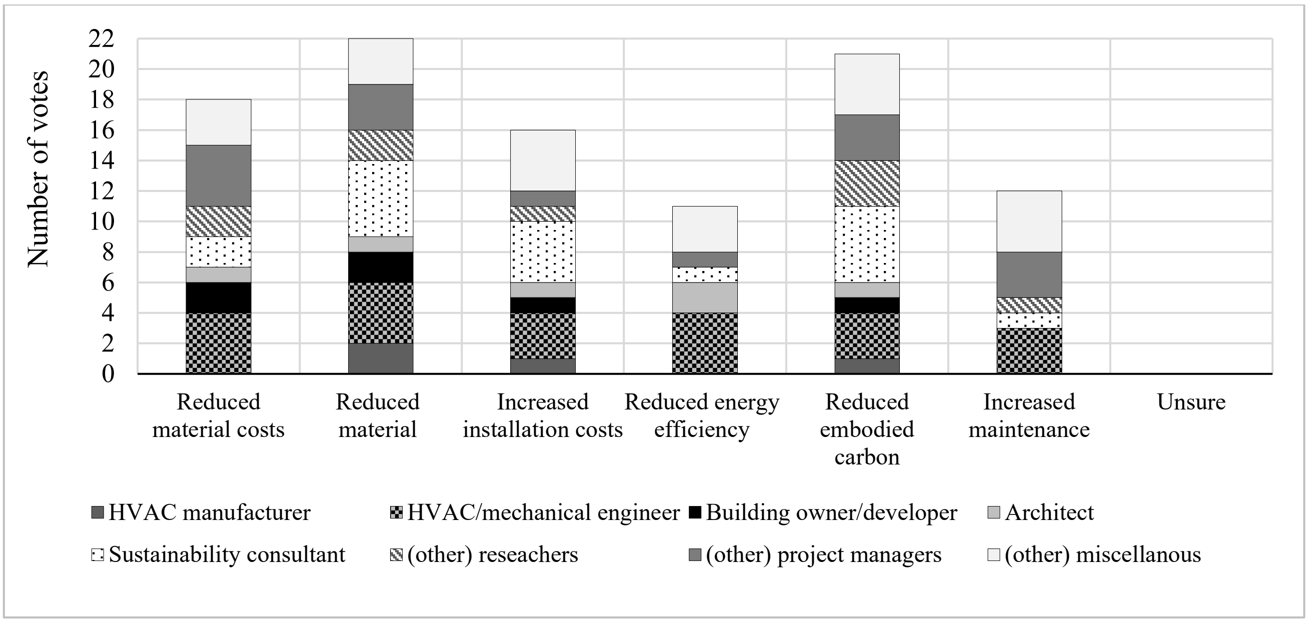

Figure 12. What outcome would you expect when implementing the reuse of HVAC components?

3.2 Responses from HVAC-related professions

The following section focuses on responses from professionals involved in HVAC manufacturing and HVAC designs. Respondents were asked to select which HVAC components they felt had the highest potential for reuse based on their experience. According to the findings presented in Figure 13, air ducts emerged as the unanimous choice, with all eight respondents selecting them. Diffusers and AHUs were the next most popular choices, with 4 out of 8 respondents making this selection.

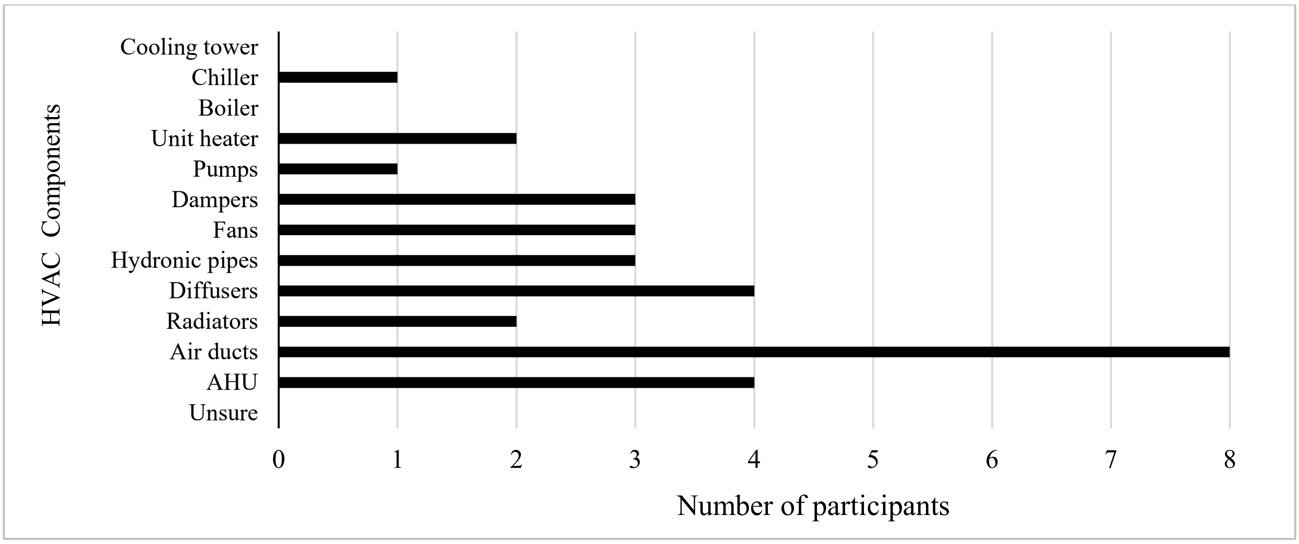

Figure 13. Which HVAC components have the highest potential for reuse?

Participants were asked to select which steps, based on their experience, could promote the reuse of existing HVAC components. The results are shown in Figure 14. Testing for reusability was the most common answer, followed by refurbishment and designing for longevity (i.e. using durable material). Two participants also selected "other" and highlighted concerns about the effectiveness of reusing HVAC components and the potential maintenance involved.

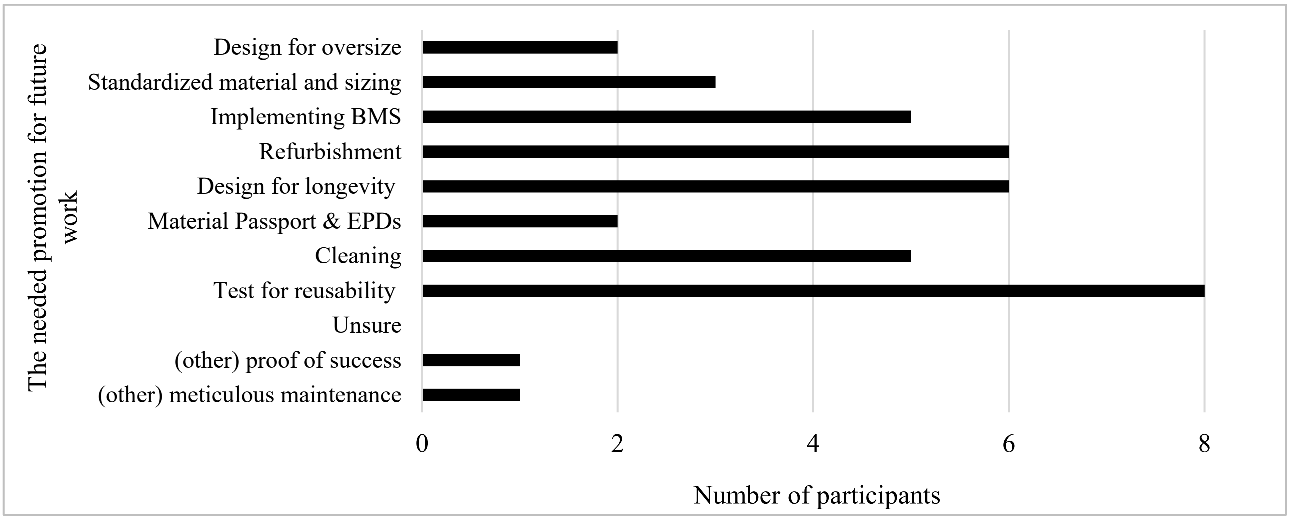

Figure 14. Based on your experience, which steps could promote the reuse of existing HVAC components?

The participants were also asked which options they felt would prevent the reuse of HVAC components. The results are shown in Figure 15. Performance uncertainty, poor conditions, and use of toxic materials were the most commonly selected options, followed by location and accessibility of equipment and components.

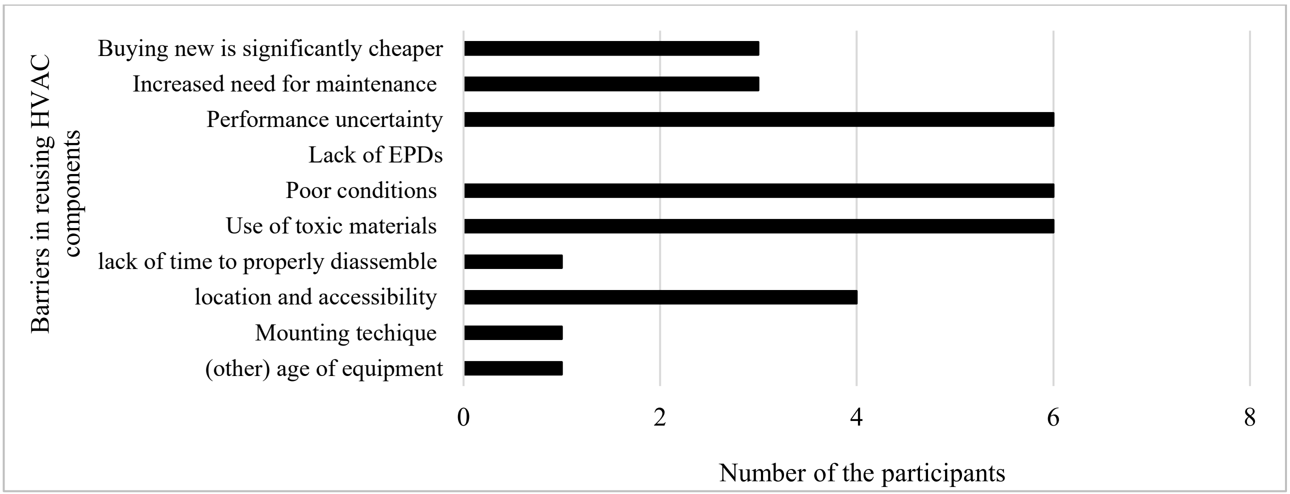

Figure 15. If a building were to redesign its HVAC system, and some of the previously existing equipment met the specifications of the new design (e.g. sizing), what factors could prevent this equipment from being reused?

3.3 Personal Interview

Table 3 shows summarised results from the personal interviews. The completed list of questions and answers and each participant's occupation can be found in Appendix D. Eight professionals were interviewed, and all were employed in Sweden.

Table 3. Summarised results from personal interviews.

Greatest Potential	Influence Parties
• Air ducts • Diffusers • AHUs	• Regulations • Building owners • Mechanical engineers • Manufacturers
Barriers	**Drivers**
• Lack of infrastructure • Increased time for disassembling • Available storage • Lack of profitability • Lack of inventory for reuse • Misaligned goals • Environmental hazards • Building culture	• Accountability • Providing performance guarantee • Climate agendas (e.g. climate declaration) • Growing interest from building owners

3.3.1 Greatest potential for reuse

All participants agreed that ventilation components had the greatest potential for reuse, confirming the survey results. Participants 3 and 7 mentioned that air ducts are simple in design and unlikely to change. Participant 2 noted that galvanised steel is durable and could outlive the building's functional life span. Participants 2 and 3 suggested that the reuse should focus on the supply air ducts, as they are likely to require less cleaning than exhaust air ducts. Exhaust air ducts could contain toxic materials, posing hazards to those cleaning them and requiring more intensive cleaning. Participant 5 mentioned that it is also possible to reuse diffusers; however, since the ducts and diffusers are ordered in large quantities, there would need to be a sufficient amount of available reuse inventory to be economically beneficial.

Participants 1, 4, 5, and 7 agreed that air handling units are also viable for reuse. While the exterior casing could remain, the fan and electrical components may need to be replaced to maintain the desired efficiencies. Unlike diffusers and air ducts, manufacturers could refurbish the AHUs and sell them for a price similar to a new AHU. Participant 5 mentioned that this practice would be economically beneficial for the supplier while environmentally beneficial for the buyer (e.g. building owner).

3.3.2 Influencing parties

Participants agree that regulations through government agencies, demand from building owners, and supply from manufacturers are required to implement reuse. Participants 2 and 7 noted that demand from building owners and establishing regulations must coincide for reuse to take hold. Participant 3 mentioned that the government must establish a sense of accountability for the contractors to ensure that the HVAC components are being reused. Participant 3 also noted that the government could be involved in the reuse process in a way that is similar to recycling and waste management. Participant 5 said that the current standards for ventilation make it challenging to reuse HVAC components as certain air flows, energy efficiencies, energy use, etc., targets must be met. Participant 5 suggested that regulators could ease the requirements on manufacturers by implementing “exemptions” and promoting design or provisions with reuse in mind. Participant 6 supported this idea, suggesting that regulations could be more “forgiving” to encourage more innovation. Participant 6 said that regulations should be more focused on how to build, promoting the idea of reuse and making deconstruction cheaper.

Manufacturers also play an influential role in executing the reuse of HVAC components. Participants 4 and 5 suggested that manufacturers could conduct visual inspections or reusability testing to provide performance guarantees. Both participants also mentioned that the manufacturers could refurbish the AHUs on-site for a new building function or off-site, intending to sell “second-hand.” Participant 1 noted that storage space is another service the manufacturer could provide to the building owners who plan on reusing their air ducts.

Participant 3 emphasised the importance of strategic planning, highlighting this as the most crucial part of reuse. If the reuse of ventilation components is considered at the project’s early design stage, the involvement of mechanical engineers would be vital. However, if reuse is proposed after the building is constructed, the contractor must ensure proper disassembly and inventorisation of the ducts.

3.3.3 Barriers

Numerous barriers to reuse exist, as the practice is uncommon in building planning and construction. All participants mentioned the lack of infrastructure hinders the practice of reuse. Participant 1 noted that disassembly would be more time-consuming than conventional methods. Participant 1 stated the current method for demolition involves using a cutting saw to detach units from the ceiling. However, if the ducts were to be saved for reuse, they must be disassembled meticulously to prevent damage, requiring more disassembly time. However, Participant 2 suggested that demolition contractors could potentially “cut around the screws” to be more time-efficient.

Interview participants also raised concerns about finding space to store ducts during renovations. Ideally, the ducts could be stored somewhere on-site or at a nearby location, as Participant 4 mentioned. Participant 1 also highlighted the logistical challenge of transporting the ducts due to their volume, which could require numerous trips to and from the storage facility.

These challenges are likely to drive up costs, highlighting the next barrier: the profitability of reuse. While reuse would save material expenses, Participants 3 and 7 emphasised that the cost of cleaning, transporting, storing, and disassembling must be lower than buying new. An initial analysis by Participant 3’s company predicts that reuse could be twice the price of buying new. It is unclear who would bear these additional costs: the manufacturer, the building owner, or the government. Participant 3 stated while everyone would be leaning on each other for reuse to work successfully, everyone would be concerned with their own financial gains.

Participant 5 also mentioned the need for a scaled-up supply of reusable components for the practice to be economically feasible. Components like ducts and diffusers are ordered in large quantities, requiring a large supply to meet demand and provide economic benefits.

Participant 5 suggested that profitability can result in misaligned goals, pointing out that the word “second-hand” implies the product is cheaper than a new product. However, this may not be in the supplier’s best interest. Suppliers would prefer to refurbish products sold at a price close to that of a new product. If this were the case, building owners would be buying refurbished equipment with the main focus of achieving a climate agenda. Many participants have emphasised that costs are the main driver, and if a refurbished product is nearly the same price as a new one, building owners may be more inclined to buy new.

There are also environmental and health concerns with the reuse of HVAC components. Participant 3 mentioned that old ducts from the 1970s-1980s have glass wool insulation composed of toxic materials, potentially harming workers handling them. Participant 6 mentioned the presence of asbestos and chromium 6 would also need to be considered. These hazardous materials could make a building's HVAC system ineligible for reuse.

Participant 2 emphasised that the emissions associated with reuse, such as transportation to and from storage facilities and cleaning, must be lower than emissions from using new components.

Finally, another barrier is the culture surrounding building and planning. Participants 2, 3, and 4 mentioned the challenge of implementing new installation methods. Participant 2 explained that in the context of installing HVAC systems, today's labourers are taught by the older generation, making it difficult for new practices to break this cycle. Participant 3 stated that people are more comfortable doing what they know will work, and Participant 4 stated that businesses are slow to change.

3.3.4 Drivers

Many barriers can become drivers if the necessary parties address concerns regarding reuse practices. Participant 3 suggests regulations could hold contractors accountable for ensuring that products are being reused. The regulations could also mandate the manufacturers to provide a performance guarantee for reused equipment and components. In the case of air ducts, participants suggested a visual inspection to ensure there is no leakage and the ducts are thoroughly cleaned.

Participants 6 and 8 believe BBR's climate declaration is a potential driver as it limits embodied carbon in new construction. This would incentivise building owners to demand it, which would result in manufacturers providing it.

Participants 7 and 8 mentioned that the government would have to incentivise the reuse of HVAC components and likely subsidise the practice in the short term, like many innovations that enter the market.

3.4 Inventory of ventilation components

Figure 16 shows the GWP for all components in the case study. The results indicate that CO2 emissions from mechanical equipment (AHU) have the highest impact. Ducts have the second-highest impact. "Others" were air hoods, overflow units, and sound absorbers.

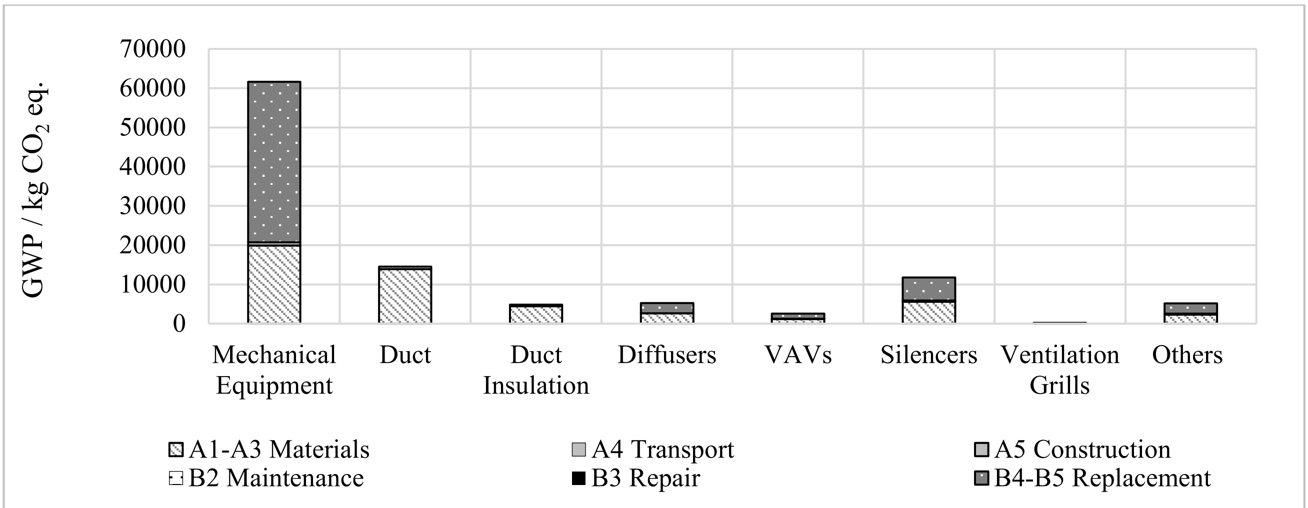

Figure 16. Global warming potentual of all components in the ventilation system in case study.

3.5 Base case office vs. historic adaptive reuse

3.5.1 Life cycle assessment

The GWP results are shown in Figure 17. Stages A1-A3 had the largest contribution in both scenarios, contributing roughly 97,7 % of CO_2 emissions. The adaptive reuse scenario had a 4 % reduction in emissions in the A1-A3 stages compared to the base case office. The impact from stage A4, transportation to the construction site, was reduced by 2 % in the adaptive reuse scenario due to fewer air ducts being transported to the site. The C1-C4 stages account for the air ducts discarded from the decommissioned dance studio. Because most air ducts were reused, the impact from disposal was reduced by 99 %. The reuse scenario did have emissions from the B2 stage from uninstalling and reinstalling the air ducts. The emissions from this category had a nearly negligible impact, accounting for only 0,10 % of the total emissions in the adaptive reuse scenario. Overall, the adaptive reuse scenario had a 4 % reduction in CO_2 emissions compared to the base case. The carbon emissions for each stage can be found in Appendix H.

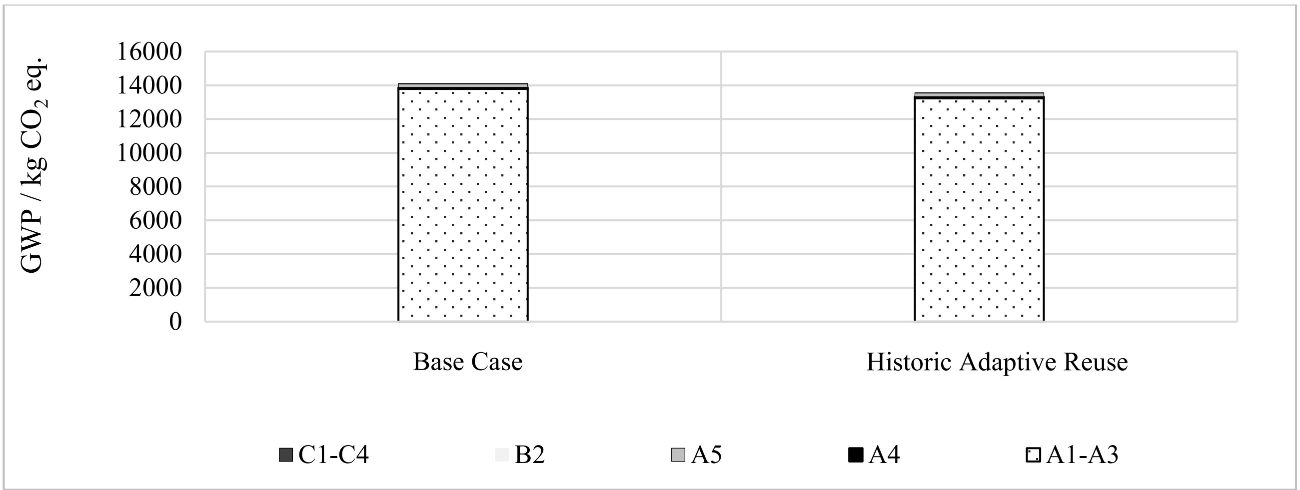

Figure 17. The global warming impact of base case office compared to adaptive reuse office.

3.5.2 Life cycle costs

Figure 18 compares the LCC of the base case scenario and the adaptive reuse scenario. The base case office design had an approximate total cost of 615 700 SEK, while the adaptive reuse scenario had an estimated total cost of 602 700 SEK. There are approximately 20 600 SEK in material cost savings. However, there is only a net saving of roughly 13 000 SEK when considering the additional costs of disassembling and reinstalling the existing air ducts for reuse. Therefore, for reuse to be profitable the cost of cleaning and reusability testing would have to be lower than 13 000 SEK.

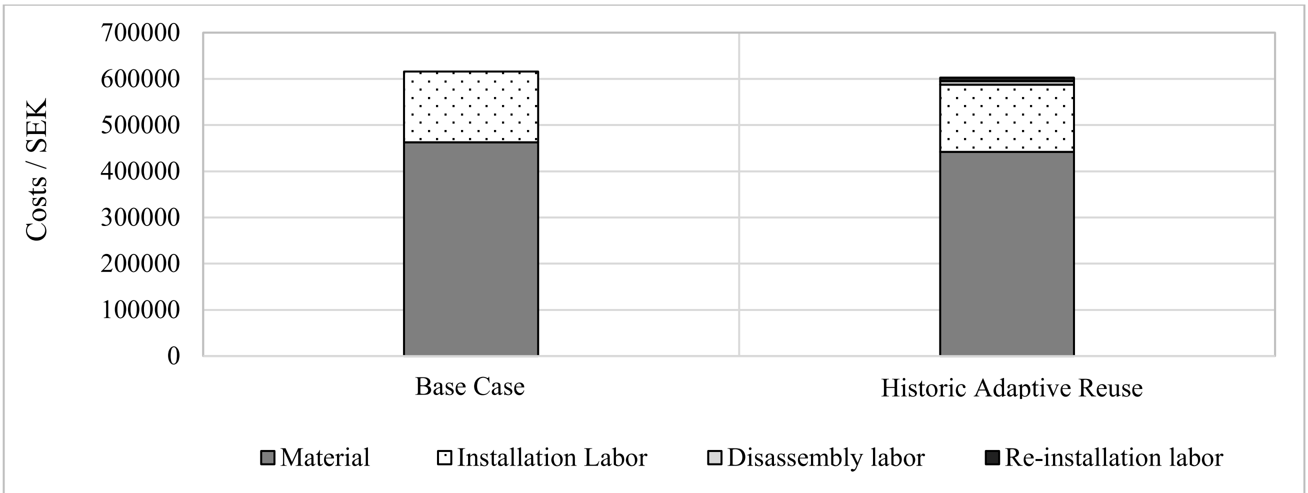

Figure 18. Life cycle costs of base case office compared to adaptive reuse office.

3.6 Base case apartment vs. future adaptive reuse

3.6.1 Life cycle assessment

In the apartment scenario, 92,25 % of the existing office ductwork was reused for the adaptive reuse apartment design. In comparison, 7,75 % of the existing office ductwork is discarded, making the adaptive reuse apartment scenario 100 % reused material. Figure 19 shows that the GWP impact for the base case, with all new ductwork material, has a significantly higher environmental impact than the adaptive reuse scenario. Because the adaptive reuse design uses 100 % reused material, there is no impact from the A1-A5 stages. The impact from the adaptive reuse scenario (fixed) mainly occurs during stages C1-C4 from the 7,75 % that is discarded. The B2 stage also impacts the results of reinstalling the ducts. The emissions were reduced by 99,8 % in the adaptive reuse scenario (fixed). Even when the ducts were fully disassembled and reinstalled, the environmental impact remained significantly lower than the base case (98%). Neither case included the impact of cleaning.

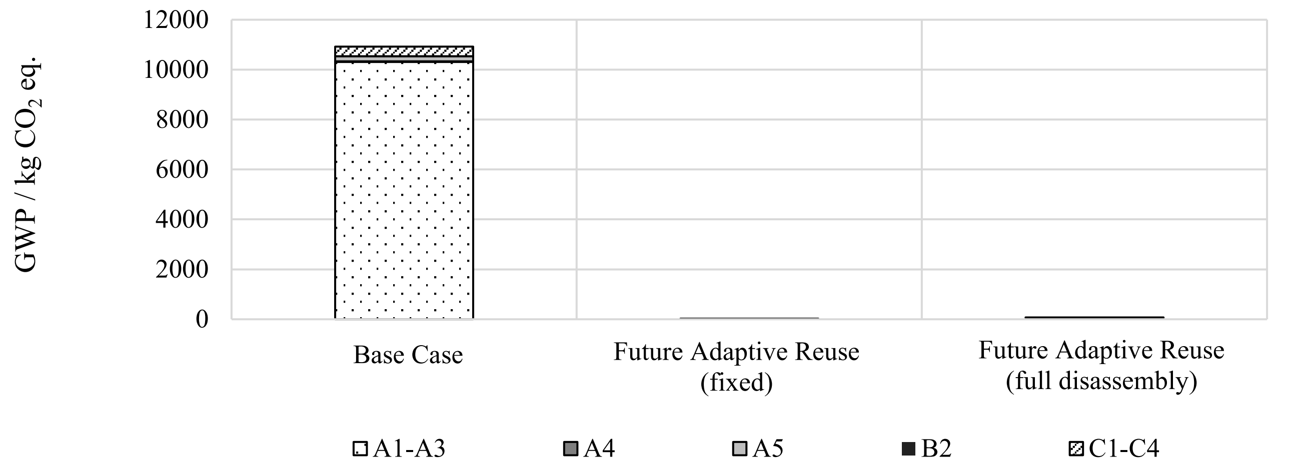

Figure 19. The global warming impact of base case apartments compared to adaptive reuse apartments when ducts are fixed or fully disassembled.

3.6.2 Life cycle costs

Given that the adaptive-reuse apartment scenario is entirely made out of existing air ducts, there are no costs for buying new material, as shown in Figure 20. The cost for disassembling and reinstalling was low since most of the existing air ducts could remain in their existing positions, while a few air ducts needed to be removed and reinstalled in areas with inadequate air supply. The estimated total cost for the base case was 562 500 SEK. Compared to the 5 100 SEK total costs of the adaptive reuse scenario, there is a 99 % reduction in costs. Costs were also estimated in case all the ducts were required to be dismantled and cleaned. In this case, the costs would be roughly half the base case costs, 273 000 SEK.

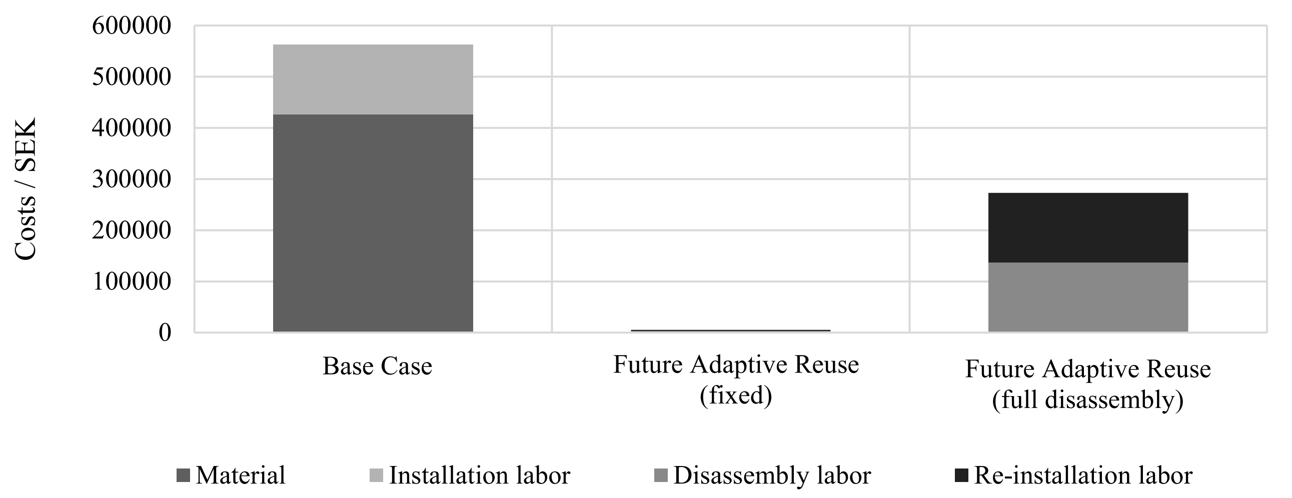

Figure 20. Life cycle costs of base case apartments compared to adaptive reuse apartments when ducts are fixed or fully disassembled.

3.6.3 Potential cost of storage

Figure 21 shows the cost of storage over two years. Today, it is estimated to be 12 SEK per m^2 per month. At today's price, the cost of storage over two years would be roughly 61 400 SEK. At a 7 % inflation rate, the total price would be 112 500 SEK. In either case, adaptive reuse would still be more economically beneficial when the storage cost is added to the LCC.

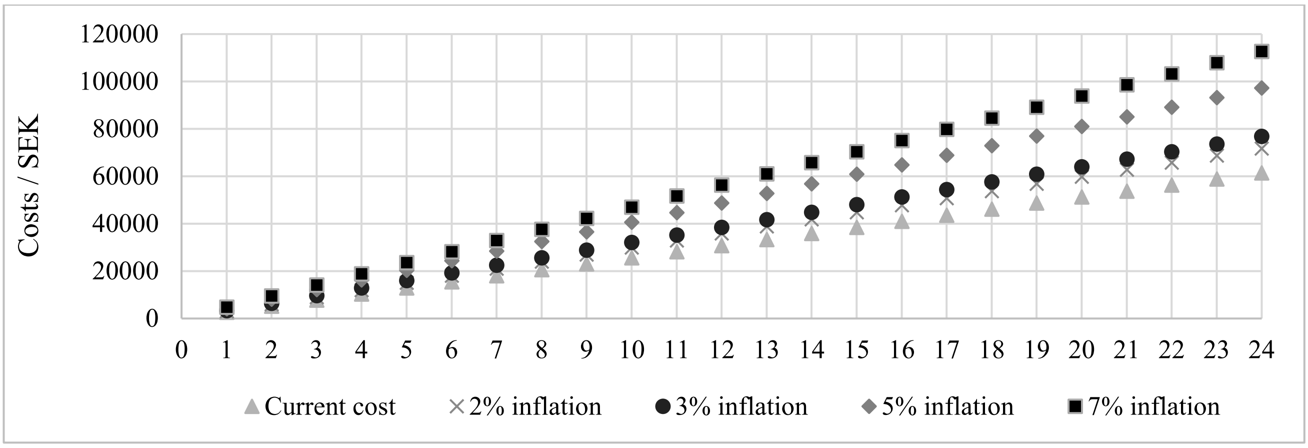

Figure 21. Estimated cost of storage considering inflation.

3.7 Reference Point

3.7.1 Life cycle assessment (LCA)

Figure 22 presents the CO_2 emissions of 1 kg of duct under various adaptive reuse scenarios. Depending on the reuse scenario, the CO_2 emission varies from 0,1 kg CO_2 eq. to roughly 8 kg CO_2 eq. The findings show that the highest environmental impact occurs during the production stage, A1-A3, with minimal emissions attributed to maintenance or transportation. Therefore, increased reuse has the potential to reduce CO_2 emissions significantly, particularly in stages A1-A3. In addition, this graph could assist practitioners in estimating GWP emissions for different adaptive reuse scenarios. The provided formula, Equation 1, could be used in order to assess the final carbon emission of the other projects based on their adaptive reuse scenario; therefore, if the GWP result of the new project was motivating enough or if any future incentives are implemented, practitioners could evaluate their GWP emissions and decide whether to start reusing ducts adaptively.

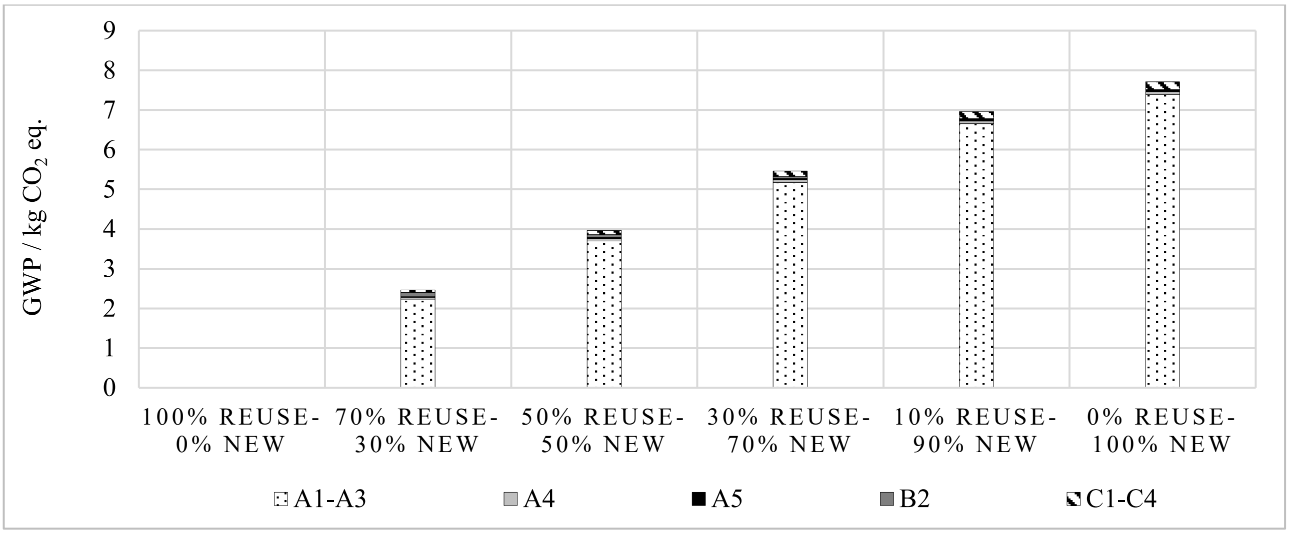

Figure 22. CO_2 emissions per 1 kg of duct from various reuse scenarios.

3.7.2 Life cycle costs (LCC)

Figure 23 shows the cost of reusing 1 m of the duct. The necessary storage area increases as duct size increases, resulting in higher costs. The graph considers storage cost, transportation cost, and dismantling cost. This graph could help manage the budget for building developers and manufacturers if they want to initiate adaptive reuse practices and store ducts outside the building site during different time periods. The cost of reusing 1 m of ducts with different diameters could vary between 1 SEK for one month to 90 SEK in 12 months. If the total length of reused ducts in each project is determined, the following graph can provide an estimation of reusing ducts.

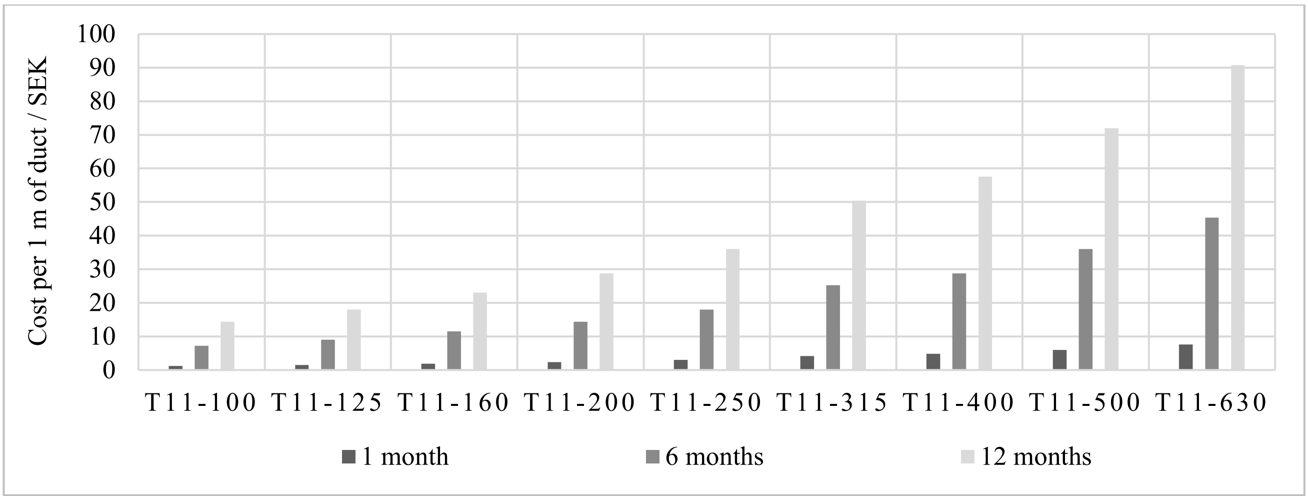

Figure 23. Cost of storing 1 m duct depending on duct diameter.

4 Discussion

4.1 Suggested HVAC components for reuse

Air ducts, diffusers, and AHUs were the ventilation components selected for reuse when discussed in the survey and interviews. Table 4 shows the advantages and disadvantages of reusing each component based on the discussions with HVAC professionals.

As mentioned before, the steel in air ducts is durable and can outlast the functional life span of a building. The material composition of the ducts is simple and would need relatively minor refurbishment, such as replacing the sealant. Furthermore, the concern for performance deterioration or new designs entering the market would not be present since the product itself is not electrified. However, some downsides could exist. According to the interview participants, their resale value would be hard to determine because air duct costs are relatively low. It could be so low that it would not bring any financial gains to the seller. Additionally, there would have to be an inventory of second-hand ducts at a scale meeting the demand. Logistically, air ducts would require more time to disassemble, and their bulky volume would require a large storage area.

Diffusers are also candidates for reuse as they are simple in design and require a much smaller storage area than air ducts. However, like the air ducts, they would have a low resale value and require a high inventory as these products are ordered in large quantities. The amount needed would have to be sufficient for the building owner and seller to obtain financial gains.

Finally, AHUs could also be reused. The steel casing of AHUs makes them a long-lasting piece of equipment. The equipment also has the potential for a high resale value, which would be in the interest of a seller or manufacturer. The electrical and motorised components in the interior can be replaced with new, more energy-efficient parts to enhance the performance of the AHU compared to that of a new one. Replacing these electrical parts can be costly and may not make financial sense for the manufacturer or the buyer. Moreover, upgraded equipment, such as AHUs, with better performance regularly enters the market and could overshadow second-hand equipment.

Table 4. Advantages and disadvantages of reusing air ducts, diffusers, and AHUs.

Component	Advantages	Disadvantages
Air ducts	Durable Simple materials Not electrified Consistent design	Low resale value Time intensive to disassemble High inventory Large volume
Diffusers	Small volume Simple design	Low resale value High inventory
AHUs	Durable casing High resale value	More innovative products are available Replacement of electrical components

4.2 Industry perspective on reuse

Figure 24 illustrates how implementing reuse could be achieved across various disciplines in the building industry, as indicated by the survey and interviews. Government regulations were deemed important by all parties involved. Manufacturers and building owners believe these regulations would incentivise the demand for reusable HVAC components. On the other hand, manufacturers perceived government involvement as necessary to aid in accountability and establish guidelines for manufacturers to adhere to. This could involve enhancing infrastructure for reuse or modifying regulations to facilitate easier selling or designing with reuse in mind. With regulations incentivising demand, building developers would subsequently increase demand, prompting manufacturers to supply accordingly. Simultaneous action in supply and demand for reusability is necessary for mutual benefits for all parties involved.

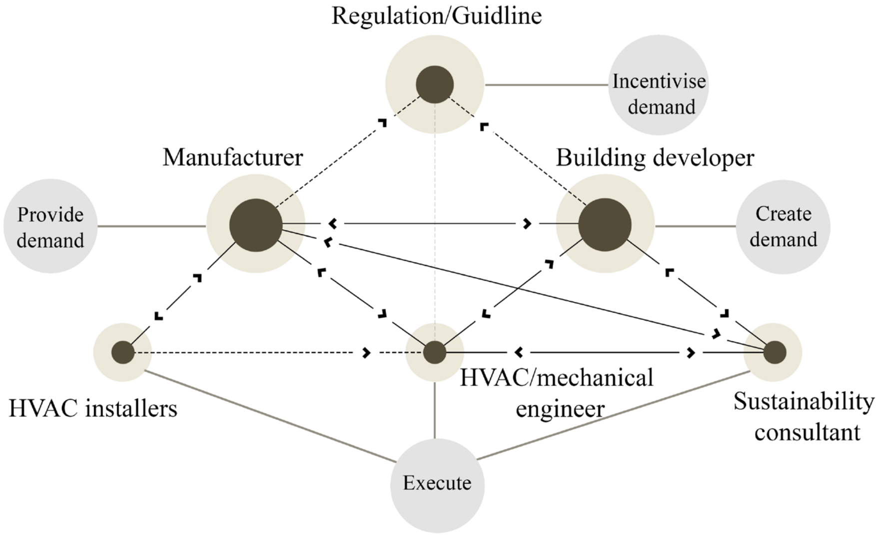

Figure 24. Map of how various stakeholders in the building industry would rely on one another to apply reuse of HVAC components.

HVAC installers, engineers, and sustainability consultants would execute the demand. Engineers would also heavily rely on government regulations to ensure the designs meet the requirements. Sustainability consultants would play a key role in evaluating the environmental benefits of reusing the ducts to reduce overall embodied carbon impact. This would require manufacturers to have EPDs for all products involved.

4.3 Suggestions for implementing reuse

Figure 25 provides suggestions on how to mitigate the barriers expressed by interview and survey participants. A table in Appendix K provides an overview of identified barriers and challenges.

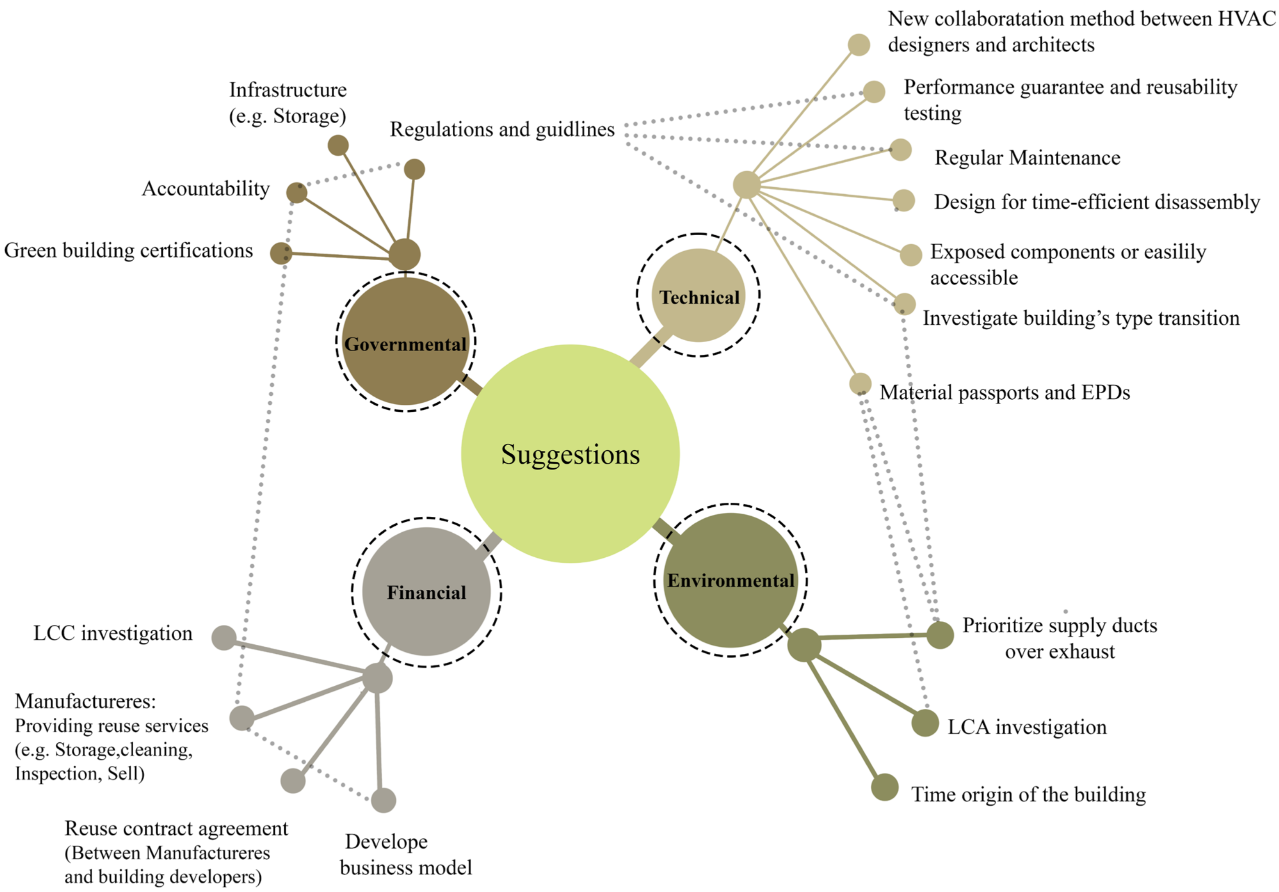

Figure 25. Suggested solutions to mitigate challenges of HVAC reuse.

4.3.1 Technical suggestions

Design for time-efficient disassembly

Recommendations to mitigate technical barriers include implementing time-efficient disassembly methods. This could involve incorporating exposed air ducts or equipment in easily accessible areas. Manufacturers could design air ducts to eliminate the need for unscrewing, having a more “Lego-like” design. Together, this could reduce the time and potential costs of disassembling.

Performance Guarantee

Several steps can be taken to ensure a performance guarantee. Maintenance procedures must be meticulously followed to ensure equipment longevity and adequate function. Additionally, reusability testing could be conducted, such as inspecting air ducts for signs of leakage, dents or rust. Manufacturers could also offer a special type of warranty for equipment being reused or intended to be reused in the future by the building owner. Material passports can assist with performance guarantee as this document would include the material composition and previous product use. Such information could be helpful when determining whether a component can be reused.

Multi-disciplinary collaboration

HVAC designers and architects must collaborate to ensure a building’s floor plan and ventilation can easily be adapted to a new function. Architects should adjust the floor plan to align with the airflow distribution established by the ductwork design. Another consideration is the number of access points; in the case study, tenant access points influenced the number and size of apartments.

Building type consideration

The transition of building types must be investigated to determine project feasibility. For instance, assessing whether the new function requires higher or lower airflow is essential. If the new airflow demand exceeds the original one, redesign may be necessary. Conversely, existing systems could be sufficient if the airflow demand is lower.

4.3.2 Environmental suggestions

Considering hazardous material

Environmental suggestions focus on avoiding exposure to hazardous materials and verifying the environmental benefits of reuse. Establishing specific periods and origins when HVAC equipment is prohibited from reuse would protect workers from handling equipment exposed to toxic materials like asbestos. This would make it easier for building owners to decide if a building is a candidate for reuse.

Prioritising supply air ducts

It is suggested that supply air ducts be prioritised over exhaust air ducts, as they are less likely to be exposed to toxins and may require less cleaning. However, it is important to investigate where the ducts are being reused. For example, if the origin of ducts is a gym or laboratory, it may be unfavourable to reuse them due to potential exposure to harmful substances or increased cleaning requirements. Material passports could assist with this as they would track the duct's previous building function.

LCA investigations

Lastly, conducting a LCA investigation is recommended to evaluate environmental savings. Each building project is unique, requiring consideration of different services to facilitate reuse. It may or may not conclude that reuse is the optimal decision. To complete an LCA, EPDs must be made available by the manufacturers for all components considered for reuse.

4.3.3 Financial suggestions

Business model development

A prominent challenge, mainly for manufacturers, is the lack of profitability. Since this practice has never been done before, there is no assurance of financial gains from reuse, requiring a new business model. Manufacturers could supplement the costs of selling new equipment by providing reusability services, such as storage, cleaning, inspection, or selling second-hand equipment. This might also involve a special agreement with building owners wherein systems are "leased" from the manufacturers. Upon decommissioning the building, manufacturers could reclaim the equipment for resale, or if the building owner intends to reuse the system for a different function or location, manufacturers could assist in the process.

LCC Investigation

Building owners should conduct an LCC analysis to determine the economic viability of reuse for their specific project. As mentioned, each project is unique, and reuse feasibility may vary.

4.3.4 Governance suggestions

Development of regulations and guidelines

Regulations and guidelines play a central role in facilitating the reuse of HVAC components. Regulations and guidelines could establish the time periods from which HVAC equipment cannot be reused. It could also set guidelines for which type of building's HVAC components can be reused, considering technical and environmental factors. Additionally, regulations and guidelines could specify maintenance and reusability testing requirements to ensure reused equipment performs as effectively as new equipment. Such regulations would also establish accountability, not only for manufacturers but also for building owners and contractors. Personal interviews and surveys emphasise the need for contractors to be held accountable for ensuring that equipment is reused as intended. At the same time, regulations and guidelines are crucial for incentivising the reuse of HVAC components. Green building certifications like Miljöbyggnad and BREEAM could also encourage building owners to prioritise reuse.

Needed infrastructure

Another recommendation is establishing infrastructure that promotes reusability, such as storage facilities. The government could establish its own storage facilities or encourage other businesses to provide such services. Results indicate that storing on-site would offer significant economic benefits; therefore, the government could consider providing on-site storage containers.

4.4 Environmental and economic benefits of reuse

The extent to which ducts can be reused greatly influences the possibility of the process. If only a tiny fraction, say less than 5 %, of the ducts can be effectively reused in the new project, the cost-effectiveness of such reuse is minimal. This stems from the considerable labour involved in disassembling and assembling the ducts for cleaning purposes. Moreover, the expenses incurred in transporting these ducts back to the manufacturer might outweigh any potential benefits derived from reusing them. Additionally, the reduction of environmental impact from such limited reuse is not compelling enough to incentivise building developers to adopt this approach.

However, the outcomes differ with the increase of reuse fraction; in the **Apartment Future Adaptive Reuse** case, more than 92 % of the ducts from the office can be effectively reused, owing to their acceptable condition in this case study. Here, both cost and environmental impact see substantial reductions. Even if storage space is required to accommodate many ducts awaiting reuse, initiating adaptive reuse practices proves highly advantageous. There would be significant financial savings if storage is unnecessary and the ducts are not cleaned. However, the costs can increase if storage and or cleaning are needed. This would also include the labour costs of loading and unloading the ducts from the truck.

The findings and previous interviews indicate that storage may not always be required, especially if the site already has enough space to accommodate the ducts. When ducts are being reused within the same project, storage can become unnecessary, and cleaning can be conducted without disassembly. However, these factors must be considered if storing and transportation are necessary for reusing the ducts later in the project. The logistics of storage and transportation depend significantly on the distance to the storage facility and the duration of storage, both of which can influence the overall feasibility and cost-effectiveness of the reuse process.

5 Conclusion

The overall perception of the reusability of HVAC components was positive, with many participants expressing it as a "good idea" and having "great potential" while simultaneously having scepticism over the financial outcomes and whether the building industry could implement such a practice. Additionally, environmental, economic, technical, and governmental barriers need to be addressed. These responses emphasise the need for the government to incentivise and guide the building industry in implementing the reuse of HVAC components through regulations, recommendations for best practices, and developing an infrastructure. Doing so would encourage building owners and manufacturers to implement reuse and improve building habits.

The survey and interviews agreed that ventilation components, specifically air ducts, can be reused. Air ducts are made with few materials, and the design will likely stay the same, making them ideal for reuse in future projects. Also, ductwork occupies a large area of the building space and ventilation design, indicating that reusing them could have high savings. Air ducts are not motorised or electrified, meaning there is no need to update any electrical wiring or be concerned that the efficiency could deteriorate.

While reuse can provide financial savings for a building owner, it can also be an industry disrupter for HVAC manufacturers, as they would gain less financially from the stakeholders purchasing new products. Therefore, manufacturers must develop a business model to supplement the lost profits through services that would assist HVAC designers and building owners in reusing. Furthermore, manufacturers could develop a circular market where they resell their used products.

Reuse and adaptive reuse of HVAC components have been shown to have positive financial and environmental impacts. However, it highly depends on the building type and how much is available for reuse. In the office scenario, the small savings resulted from a low quantity of ducts available for reuse, as the dance studio had roughly 88 % smaller area than the office. If only 4 % of the ducts are reused, it may not be worth the inconvenience for the building owner to disassemble and clean the reused ducts. Therefore, it would be more beneficial for the building owner to reuse the ducts from a space similar in size to the new project site or to find a supplier that sells reusable ducts in the needed quantity.

While the office scenario is more relevant to reusability within mixed-use buildings, the apartment scenario can be applied to single-use buildings since the air ducts remain in the same location. The apartment scenario illustrated that high environmental and financial savings can be achieved when many ducts are available. If 92 % of the office ducts were reused, achieving a 100 % reused duct design for the apartment, the costs could be halved.

Since the results did not include the impact and financial costs of cleaning and transportation to and from a storage facility, it is highly encouraged that the building owner completes these estimates before reusing air ducts.

6 Future work

A significant amount of future work can stem from this project to have a deeper and more expansive understanding of the reuse of HVAC components. The following are recommended topics:

- Implement the practice in a real-life scenario and assess the system's performance.
- Evaluate how an oversized air duct system performs in an adaptive reuse scenario.
- Investigate how BMSs can help develop adaptive reuse practices.
- Investigate the reuse of other HVAC components.
- Investigate environmental impact from cleaning and transportation to storage facilities.
- Further development and guidelines for LCAs in adaptive reuse scenarios.

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Appendix

Appendix A

Survey

General Questions:

1. *In what country are you currently employed?*
2. What role do you play in the construction industry?
   - *Architect*
   - *HVAC manufacturer*
   - *HVAC/mechanical engineer*
   - *HVAC installer*
   - *Facility/Property Manager*
   - *Building owner/developer*
   - *Sustainability/environmental consultant*
   - *Urban planner*
   - *Other*
3. *Briefly describe your thoughts on reuse of HVAC components. (optional)*
4. *Select which parties would have the greatest role in executing on this. In other words, which party would you rely on to implement reuse of HVAC components?*
   - *HVAC manufacturer*
   - *HVAC/mechanical engineer*
   - *HVAC installer*
   - *Government regulations*
   - *Building owner/developer*
   - *Facility Manager*
   - *Architect*
   - *Sustainability/environmental consultant*
   - *City planner*
   - *Unsure*
   - *Other*
5. *What framework/infrastructure do you need to start this practice?*
   - *Regulations and guidelines*
   - *Market demand*
   - *Facilities to hold reusable HVAC components (e.g. material banks, construction depots)*
   - *Material passports or EPDs*
   - *Unsure*
   - *Other*
6. What barriers/challenges exist with the reuse of HVAC components?
   - *Governance (lack of collaboration and guidelines, etc.)*
   - *Environmental (use of toxic materials, etc.)*
   - *Technical (sound level, friction loss, SFP, accessibility, life span, etc.)*
   - *Economic (costs, influence on job market, etc.)*
   - *Unsure*
7. *Briefly explain your reason for the chose answers of the previous question.*
8. *What outcome would you expect when implementing reuse of HVAC components?*
   - *Reduced material costs*
   - *Reduced material*
   - *Increased installation costs*
   - *Reduced energy efficiency*
   - *Increased maintenance*
   - *Unsure*
   - *Other*
9. *Please elaborate on any answers you feel need further explanation. If you feel this survey did not touch on an important topic, please address them here.*

Questions for HVAC related professions

1. *Briefly describe your job position.*
2. *Based on your experience, which of the following components do you believe have the greatest potential for reuse?*
    - *AHU*
    - *Air ducts*
    - *Radiators*
    - *Diffusers*
    - *Hydronic pipes*
    - *Fans*
    - *Dampers*
    - *Pumps*
    - *Unit heaters*
    - *Boiler*
    - *Chiller*
    - *Cooling tower*
    - *Unsure*
    - *Other*
3. *Briefly explain why you chose the option(s) you did.*
4. *Based on your knowledge, how would you approach the HVAC design in a new building so that the HVAC components could be reused if the building is to transformed after 10 years?*
5. *Based on your experience, which steps could promote the reuse of existing HVAC components?*
    - *Testing for reusability (e.g. retro-commissioning, testing & balancing, etc.)*
    - *Cleaning*
    - *Material passport or EPDs*
    - *Design for longevity (i.e. more durable)*
    - *Refurbishment (e.g. replace insulation, sealants, etc.*
    - *Implementing building monitoring system (BMS)*
    - *Standardize materials and sizing*
    - *Design for oversize*
    - *Unsure*
    - *Other*
6. *If a building were to redesign their HVAC system, and some of the previously existing equipment met the specifications of the new design (e.g. sizing), what factors could prevent this equipment from being reused?*
    - *Mounting technique*
    - *Location and accessibility of HVAC components*
    - *Lack of time to properly disassemble*
    - *Use of toxic material*
    - *Poor condition (e.g. rusting)*
    - *Lack of EPDs*
    - *Performance uncertainty*
    - *Increased need for maintenance*
    - *Buying new is significantly cheaper*
    - *Other*

Questions for Architects

1. *Briefly describe your job position*
2. *When designing a building, how much consideration is given towards to the placement of HVAC system? The purpose of this question is to determine how much of an effect the architectural design plays when designing the HVAC system to serve the building?*
3. *How can buildings be designed for better disassembly of HVAC components? (e.g. having exposed air ducts for easy access).*

Questions for building owners and urban planners

1. *Briefly describe your job position*
2. *Are obsolete buildings a current concern?*
   - *Yes*
   - *No*
   - *Unsure*
   - *Other*
3. *Have you considered transforming the building's function as an approach? For example, office into residential space?*
   - *Yes*
   - *No*
   - *Unsure*
   - *Other*
4. *Have you considered the reuse of HVAC components? (e.g. air ducts, pipes, etc.)*
   - *Yes*
   - *No*
   - *Other*
5. Briefly explain the reasoning for your previous answer.
6. *For what type of buildings are seeing the need for reuse?*
   - *Apartments*
   - *Offices*
   - *Schools*
   - *Houses*
   - *Industrial buildings*
   - *Healthcare facilities*
   - *Malls/shopping centers*
   - *Unsure*
   - *Other*
7. *What would be the best motivator for you to transform the buildings instead of commissioning new ones?*

Questions for Sustainability Consultants

1. *Briefly describe your job positions.*
2. Do you see an interest in the reuse of HVAC components? If so, in what type of buildings do you see a great potential?

Appendix B

Duct specifications and costs from Wikell's Sektionsfakta

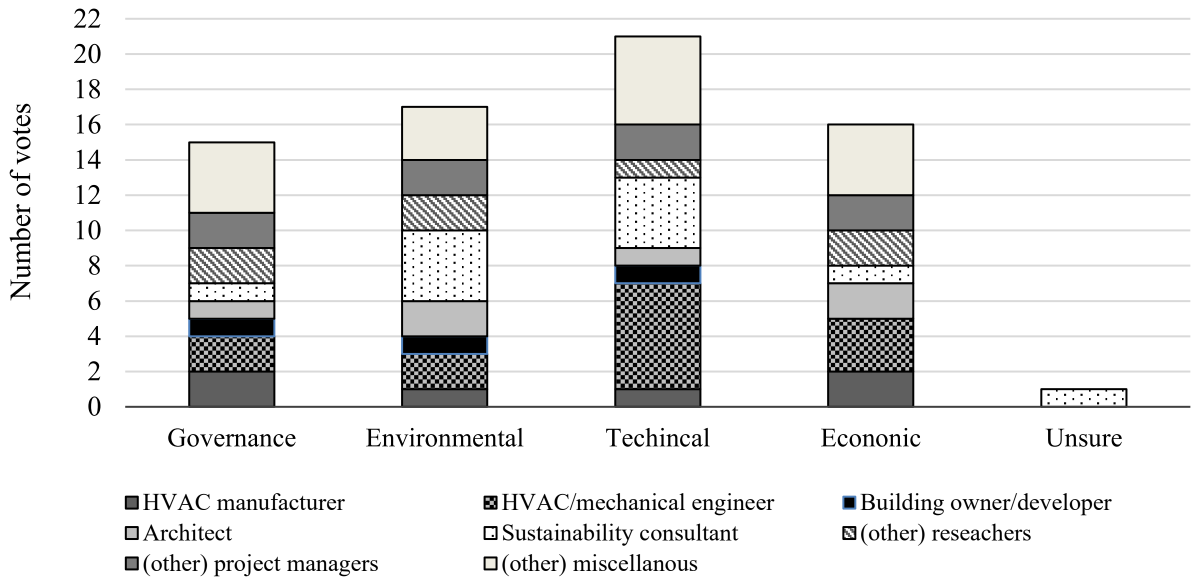
Duct Size	Total Weight / kg	Total length / m	Cost per length / SEK/m	Time of labour / h/m	Cost of labour / SEK/hr*
100	16	11.55	146.12	0.19	205
125	96	59.96	182.78	0.21	205
160	174	86.535	219.7	0.22	205
200	580	230.255	308.88	0.24	205
250	270	87.64	390	0.26	205
315	100	286.56	512.72	0.33	205
500	210	31.25	762.84	0.39	205
500	24	2.8	985.66	0.45	205
630	120	11.35	1208.74	0.52	205
1600 x 600	252	7	4854.33	1.23	205
1500 x 600	10,4	3.2	4674.54	1.19	205
1400 x 800	176,8	5.2	4854.33	1.23	205
400 x 200	32	4	1577.16	0.45	205
400 x 150	4	0.5	1445.73	0.42	205
Bends		**Total amount / pcs**	**Cost per fitting / SEK/pcs**	**Time of labour / h/pcs**	**Cost of labour / SEK/hr***
125		9	24.219	0.01	205
160		12	33.0165	0.01	205
200		28	43.47	0.01	205
250		6	143.865	0.01	205
315		14	80.523	0.01	205
400		9	70.422	0.01	205
T's		**Total amount / pcs**	**Cost per fitting / SEK/pcs**	**Time of labour / h/pcs**	**Cost of labour / SEK/hr***
315/315/160		15	392.6768	0.04	205
315/315/200		67	392.6768	0.04	205
160/160/160		1	159.3416	0.04	205
315/315/125		16	392.6768	0.04	205
250/250/200		8	289.7576	0.04	205
400/400/200		18	286.902	0.04	205
400/400/400		10	286.902	0.04	205
400/400/315		6	286.902	0.04	205
400/400/250		1	286.902	0.04	205
250/250/125		2	289.7576	0.04	205
250/250/250		1	289.7576	0.04	205
315/315/315		2	392.6768	0.04	205

* additional 295% surcharge

Appendix C

General Responses

Briefly describe your thoughts on reuse of HVAC components. (optional)
1. Good idea. 2. I think the reuse of HVAC components has great potential, but would be very situational and could not be applied for every case. 3. I believe there is a strong potential in the reusability of HVAC components. But it must be placed in a guideline or certificate for the building while planning 4. I think this is a very important and good topic. However, I think it might be hard to adapt in the type of projects my company works with (clean rooms). This probably works better with office, commercial and residential buildings. 5. Beneficial in some cases, sometimes not always cost effective. Difficult to repurpose old systems to perform up to todays standards. Ductwork, grilles, etc. is fairly standard over the years, but new VAVs, FCUs, etc. are far better in terms of energy efficiency, maintenance, and performance. 6. I think it can be done but it might not outweigh the benefit of just installing a new system. I think hang components can be recycled and reused for other applications maybe not have related. Air conditioning and heat pose a lot of wear on parts if they could be ultra-resistant to these and other general wear they could certainly be reused if functionality and fit resemble new installations. Would have to standardize function and installation. 7. There is certainly a huge lack of knowledge and understanding of this question 8. It is a necessity when renovating buildings, since it keeps the cost down, as well as the environmental impacts and the amount of time a project takes. 9. I think its would be a good idea. I don't know the specifics. 10. Refer to previous responses. 11. Many products may be expired and cannot be used or that one does not dare to use them again due to the risk of leakage, regarding channels, these are bulky and difficult to stock before re-use 12. HVAC component reuse offers numerous environmental benefits, but it also presents various challenges. Some products, such as radiators and ventilation ducts, are easier for reuse. However, electrical products like pumps, heat exchangers, fans, and heating coils pose challenges due to technical complexities and unique variations. 13. Reusing existing systems is always an option to be explored but will vary on every single job. Many factors come into deciding if the existing system can be modified for the new application. Age & condition of existing equipment should always be looked at before making this decision. The hurdle with retrofitting an existing system is that it was designed and installed to heat/cool the space differently than the new proposed space. In my experience, customers go for these options due to the cost being lower but that is not always the case. You must also look at it from an efficiency standpoint and figure out if modifying an existing system will be beneficial in the long run. 14. This is a future need, but we need to investigate and optimise what to reuse and how. 15. It's a good idea if the components still are functioning and not too old. It depends on what condition the components are in. 16. The reuse of HVAC components is already practised to some extent in my work. Some examples are ducts, dampers and silencers. The things can be reused as long as they have kept their performance level and if it isn't too hard to relocate or reuse from a practical stand point. 17. I have not seen any examples of that before. One of tha parts that are energy consuming is all insulation around ventilation ducts. And that part is hard to reuse. 18. It is a good idea, but there needs to be a proof that it can be done and that it is safe to do it. 19. This is a very interesting field, which I think might have a lot of potential. However, before its implementation there needs to be some research to see how can it be done. 20. It feels like it not very common to do this in the industry today, wich i think is unfortunate. 21. I believe the standardized design of HVAC components, their similar application in different building types, and durable construction make them very suitable for reuse. 22. Not sure of the possibilities to reuse HVAC components in practice
What barriers/challenges exist with the reuse of HVAC components?



Briefly explain your reason for the chosen answers of the previous question.

1. If appropriate TDD reports are not made for the assets, it's possible that the reuse of the HVAC components may lead to extra cost, occupant discomfort or/and environmental hazards.
2. Money is talking and Laws is power
3. The above-mentioned options are always tricky in the innovative ideas.
4. All of these options apply, however I feel that the greatest challenge will be technical (ensuring the reused equipment is efficient and will last) and economic (considering the potential future costs associated with old equipment)
5. It is obvious that the old components are not as useful as the new ones. So it is probable to face with more technical problems and not meeting the high environmental requirements.
6. The building industry is extremely price driven. If new build is cheaper than reusing, it will only be used if there are guidelines. Toxic material shall be replaced, all time.
7. I think this might be the main problem. The parts need to be dismantled carefully, then stored somewhere (which costs money), and then be transported back and forth.
8. Technical might also be hard given that the rules and regulations are changing from year to year.
9. Governance-lack of strict enforcement on recycled materials regulations Technical - all mechanical equipment & components from 2024 will far out perform components from 80/90s. Ductwork is the only thing that is pretty consistent. Even the insulation today is far better than back then (new system = more efficient) although your saving money/time/resources at the front end, what are the long term impacts of leaving old components in use? Economic-you'll save money on demo, but you lose money on install trying to repurpose old equipment. Also lose money on energy if you use old equipment
10. It's got to work as well if not better than new installations
11. It should be economically reasonable for property developer to engage in this, meaning that it should yield either in cost reduction or in reasonable climate impact reduction. The lack of knowledge is another barrier right now.
12. So for governance, this is where the basic change needs to happen to make sure the only choice is to reuse as much as possible. Environmental challenges include the use of poisonous or harmful materials commonly used in buildings before, which anyways needs to be exchanged. Technical challenges are as important to acknowledge since e.g. regulations on sound levels has increased the need for developing new components accordingly.
13. Owners are going to need a warranty on reused or refurbished components.
14. Reuse is not always allowed due to efficiency requirement updates in applicable codes. Also, efficiencies of older equipment tend to be less than newer equipment. The risk of equipment failure is also higher with older equipment, so Owners often opt to replace equipment when they are renovating to avoid a pricey replacement a little bit later. It's just more complex to both design for and implement reuse of existing equipment and infrastructure. I can see this working far better with an Integrated Design approach, when the designer and contractor are working more closely together.
15. Many HVAC installations become obsolete and are difficult to reuse.
16. These are the most challenges that reuse of HVAC have: Administrative costs, storage costs Insurance, warranties, lifespans Hazardous Substances Standards such as CE mark
17. Based on experience
18. Standards change all the time in this industry pushing old methods out. Refrigerants in these systems vary & change a lot as well. New EPA guidelines & codes could make older methods obsolete in the future.
19. It should probably be more "easy" to reuse, but also things like Chrome 6 must be handled by authorities.

20. Unfortunately, money leads the way. With no profit we don't have a company and work to go to. As well with the technical solutions. Old components tend to have worse results than new (sound, SFP, friction, EPD etc). And they need more maintenance. And one very important thing is that there is no warranty period for the products. That's a very big disadvantage.
21. I would say that the option of reuse is most often erased when there is some uncertainty regarding the lowering of energy use or other type of performance. The reason for that is therefore also economical aspects, as energy use can be directly connected to that. If it's cheaper to build new with time, then it will be the option to go for.
22. It's hard to sell a used system to a new customer. It's hard to verify that the system will be functional due to leakage of air or sound. normally the manufacturers will guarantee if your assembly the system according to their guidelines. used system will probably be with more and smaller components.
23. Toxic materials in HVAC are a big no. If such are detected - it is automatically impossible. Technical issues with the reuse will lead to questions regarding the competence of an HVAC engineer. Governance will come if there will be actual safe technical solutions.
24. Not enough awareness about adaptive reuse
25. There's a lot of reasons!
26. All of those issues are valid. But I would say that the main problem is the technical one: if there is no knowledge on how it can be done, then none of the other problems can be addressed.
27. I'm guessing that it sometimes can be hard to achieve the same standard with a reused HVAC. With guidelines and lower standard it can be easier. Maybe a higher standard isn't necessary, depends on the project.
28. Reuse of HVAC components needs to be mandated by the property owner/developer as contractors/designers don't have this mandate, nor any incentive to use/prescribe reused parts. Owners/developers are risk averse, and as long as guidelines and infrastructure facilitating reuse are lacking the venture may be deemed too risky. Reuse must also be less costly than building with new components for any market demand to develop.
29. Lack of guidelines, technical (case studies and proven projects), economic (the turnover compared to demolish or replacing certain parts)
30. Cost drives almost everything in the industry
31. Quite simply because they are in line with the project

Please elaborate on any answers you feel need further explanation. If you feel this survey did not touch on an important topic, please address them here.

1. I would consider investigating whether the embodied carbon savings of reuse outweigh the embodied carbon savings of using newer equipment that may be more energy efficient.
2. I think all the outcomes you have listed are all the barriers that need to be explained. Be sure to discuss insulation & sound attenuation new vs. old.
3. I think the process of reusing hvac is the biggest hurdle. Having to uninstall and keep in good condition for the next installation is difficult. Maybe robotics for installation and demolition. Lego like design easy to get off save and then reuse with the same functionality in the next application. Maybe a type of building that integrates the HVAC or uses weather elements in the area to reduce need for power generation. A building with built in air ways or air ducts where minimum damage to building will occur when installing and taking out hvac. Maybe near a windy location that catches air to use for hvac.
4. I do think installation might be a bit more expensive but that money will be saved with the reuse of components, as well as the time reduction for the project. If the components are inspected correctly, no extra maintenance should be needed, since they have to be up to standard!
5. Hopefully reusing components would not result in lower energy efficiency
6. I always look to reuse what's existing if it makes sense. Scenarios will always exist where it just shouldn't be done, even if the equipment is in good condition. BUT…. When designed & installed correctly, reusing existing equipment in a new application can still be cost effective, long lasting, & energy efficient!
7. Something I want to push is the warranty period on the product. That's a very big disadvantage and something our industry needs to sort out before companies feel safe to make reuse a standard.
8. There needs to be a guarantee from any authority be it government, scientists or someone else that reuse will work.
9. For the moment none

Responses from Architects (3)

When designing a building, how much consideration is given towards to the placement of HVAC systems? The purpose of this question is to determine how much of an effect the architectural design plays when designing the HVAC system to serve the building.

1. HVAC systems play a role in fixing ceiling heights. So even at a preliminary level, HVAC needs to be considered.
2. Considered spatially during schematic design and final coordination
3. The hardware's attention is focused on the transmitted frequency

How can buildings be designed for better disassembly of HVAC components?

1. Smaller HVAC components, easy to disassemble and assemble again

2. Intentional use of materials, simplicity and efficiency of design of HVAC components, reduce the size of ducts and hvac equipment to give greater flexibility to interior spaces
3. Certainly design easy access but also design the equipment so that it can be more accessible

Responses from building owners (2)

Are obsolete buildings a current concern?

yes’s: 1
no’s: 1

Have you considered transforming the building’s function as an approach? For example, office space into residential.

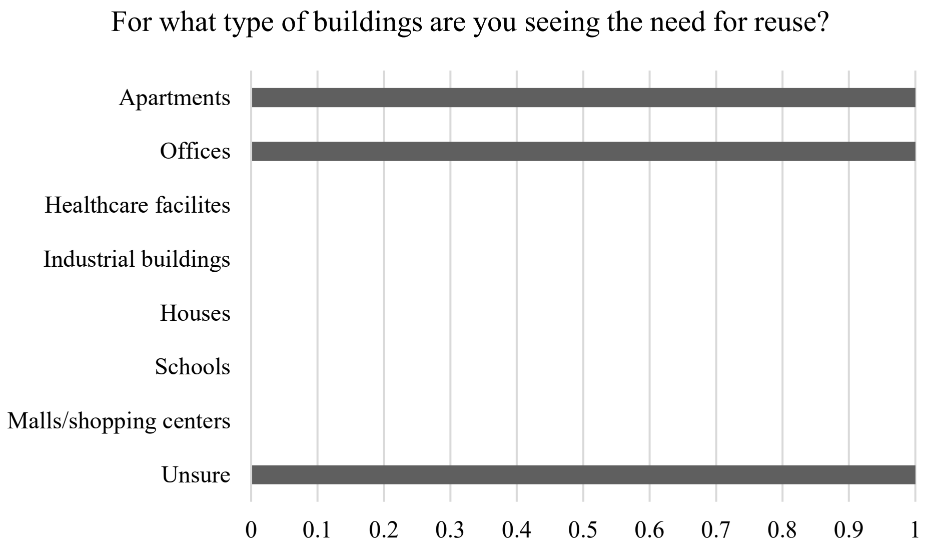
# of yes’s: 1
# of no’s: 1

Have you considered the reuse of HVAC components? (e.g. air ducts, pipes, etc.)

# of yes’s: 1
# of no’s: 1

Briefly explain the reasoning for your previous answer.

1. We wish to reduce our environmental impact
2. Not something I have control over



What would be the best motivator for you to transform the buildings instead of commissioning new ones?

1. Economic and environmental
2. Reuse of materials and stop the waste, time saving

Responses from sustainability consultants (6)

Do you see an interest in the reuse of HVAC components? If so, in what type of buildings do you see a great potential?

1. The reuse of HVAC components would very useful with regards to the LCA and LCC of large commercial projects. Example: Retails and storage spaces.
2. Yes, primarily in commercial buildings (for example office, university, laboratories, hospitals) since HVAC has a more significant proportion in this type of buildings
3. No I don't. My projects don't tend to have components available and new purchasing is assumed.
4. Yes, there is a growing interest in the reuse of HVAC components, particularly in the older residential and commercial buildings undergoing renovations.
5. Yes, most potential is in all sorts of commercial buildings, both when building new buildings and even more so in combination with residential buildings.

Appendix D

Participant 1

Industry: Building Developer
Position: Energy Engineer

Question 1: Have you reused HVAC components? Do you consider it?

Answer: Yes, we have reused radiators, air ducts, and AHUs, but only if they fit the conditions of the new building and the building function remains the same. In these instances, there is no need to demount the equipment.

Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?

Answer: Ducts, AHUS, Radiators. Not pipes because there could be a risk of rust and corrosion.

Question 3: Could you store ducts in a storage facility during building renovations?

Answer: Yes, but the ducts would require large amounts of space for storage and transporting them could also pose challenge.

Question 4: What part is the most influential regarding costs?

Answer: The manufacturer. But another challenge is the time that would be required to reuse. The current method of demolition and using a saw that cuts all the units from the ceiling. If it had to be disassembled without damaging the equipment, it would require much more time.

Participant 2

Industry: HVAC Manufacturer
Position: EPA/LCA Specialist

Questions 1: Is designing for reuse being considered on the manufacturing side? Is adaptive reuse?

Answer: It is being considered. We believe reuse of HVAC components and the whole idea of circular building is "unavoidable" and we want ahead of other manufacturing companies.

Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?

Answer: Air ducts, specifically supply air ducts as they tend to be cleaner. However, the problem is air ducts are the cheapest part, we are unsure about the profits since no body has done it yet.

The rubber sealant is said to last for 10-15 years but the duct can last longer than 15 years. If the ducts are being reused, the manufacturer would make sure the sealant is replaced, etc.

Question 3: What steps do you feel would promote the reuse of existing components? Do you feel like current components could be reused or would you have to specifically design for it?

Answer: Ensuring airtightness and energy efficiency. Cleaning before reusing and having a facility to store them. "Click" air ducts are on the market and prevent the need for screws. However, even if this type of duct is not already present, the demolition contractor can cut around the screws and event reduce waste.

For quality assurance, airtightness and cleanliness would be considered.

Question 4: What kind of barriers or challenges do you feel would prevent the reuse of components?

Answer: Culturally, people don't want to adopt new ways of doing things. The new generation is taught from the older so it's hard to break this cycle and allow for innovation, regarding HVAC installations.

Infrastructural, space is a challenge. Ducts take up a lot of space. However, this could be an opportunity for manufacturers to provide that service. The manufactures have the space and expertise to store the ducts and they can provide quality reassurance for reuse. However, it is best to focus on supply air ducts in the earlier stages as they are cleaner. Exhaust air ducts have greater potential for containing contaminants and from the administrative side, it may be too complicated to keep track of. Also, it is better to focus first on only residential and office buildings in the beginning since it is a new area and to gain insights, it is better to first focus on the building type that we believe is more plausible and requires less care, compare to industrial and hospital spaces.

Economically, ducts are cheap to begin with so the cost of disassembling, transporting, and cleaning of the reused ducts may cost more than buying new. However, we are working on establishing a business model for this and estimating costs. Perhaps government incentives, such as tax cuts, could also help to push the practice of reuse.

Environmentally, the cleaning and transportation involved with reuse should be considered. It may be the same impact as producing new.

Technically, the thickness of the steel has an influence on reusability but we don't know how and it should be further researched.

Question 5: If we want to start the practice of reuse, which parties could have the greatest role in executing this?

Answer: Government regulations and demand from building owners would have to be happening simultaneously. The manufacturers are capable of such a practice but there needs to be a market for it. Cost had a big incentive.

Participant 3

Industry: HVAC Manufacturer **Position:** Technical Manager
Question 1: Is designing for reuse being considered on the manufacturing side? Is adaptive reuse?
Answer: It is still in the theoretical phrase. It is something that is being talked about but there are no products that are necessarily designed for reuse.
Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?
Answer: Air ducts are the most ideal. They are simple in design and take up the majority of space in HVAC designs. Electronic equipment, pumps and fans, would make no sense because the efficiencies could deteriorate over time. Supply air ducts are the easiest to reuse because they will often require less cleaning. Extract air ducts would be challenging because they are probably going to be very dirty. Water related components are tough to reuse because they are welded together to ensure there are no leakage. There could also be a chance of corrosion.
Question 3: What steps do you feel would promote the reuse of existing components? Do you feel like current components could be reused or would you have to specifically design for it?
Answer: The quality assurance would consist of cleaning and checking for leakage. Quality check would be a visual inspection. Yes, current components could be reused but it would be hard. There are two types of reuse: (1) fixed reuse – keeping everything in place, no cleaning or leakage check. (2) demount reuse – disassemble, clean, and reconfigure for the new design needs.
Question 4: What kind of barriers or challenges do you feel would prevent the reuse of components?
Answer: Environmentally, old ducts from the 70s-80s have glass wool insulation which at the time had toxic materials in them. Disassembling and handling them could be harmful for the person doing it. Governmentally, there would have to be some sort of accountability that the ducts are in fact being reused if that is the intent. Perhaps the government could be involved in the reuse process, similar to how they are involved in the recycling process. Economically, based on our initial analysis, the cost of reuse, including the cost of storage, transportation, disassembling, and cleaning, could be roughly twice the cost of buying new. It is unclear who is paying for that. At the moment, it does not look like reuse of air ducts would be profitable. However, if the cost of new steel and energy goes up high enough, then reusing could be the best option. Overall, this process would require a lot of work and the business model is unclear. Culturally, if the general public wants reuse, then yes it could be done. But it's hard because people keep doing what they know and aren't comfortable with change.
Question 5: If we want to start the practice of reuse, which parties could have the greatest role in executing this?
Answer: It would start with good planning, that is the most important thing. That would be the mechanical engineers. However, there are two scenarios. If reuse is in mind from the very beginning, the reliance is on the mechanical engineers. If reuse is thought of after the building is built, then it is up to the contractor who is concern with the demounting and taking inventory to see what fits with the design. Many disciplines would need to be involved, the building owner, government regulations, etc. Everyone would be leaning on each other for the process to work. However, everyone is concerned with their own financial gains.

Participant 4

Industry: Building installations and services **Position:** Business development manager
Questions 1: Is designing for reuse being considered on the manufacturing side? Is adaptive reuse?
Answer: Yes, considering both fixed and demount reuse.
Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?
Answer: Ducts and AHUs. Components that have moving parts, for example, fans are not good for reuse.
Question 3: What steps do you feel would promote the reuse of existing components? Do you feel like current components could be reused or would you have to specifically design for it?

Answer: Ducts need to be cleaned. Preferably stored and cleaned onsite. If not onsite, then at a nearby location. The manufacturers could provide some sort of service to help refurbish the equipment. This is already done to a certain extent with the AHUs. The inspection for reuse would involve some sort of testing and visual inspection.

In terms of quality, there would need to be some sort of quality reassurance, a warranty. Some action that would solve the "legal" part.

Technically, there would need to be some sort of performance guarantee.

Economically, it needs to be profitable. It may be that recycled steel is still the best option.

Governmentally, there needs to be regulations to make this practice happen.

Question 4: What kind of barriers or challenges do you feel would prevent the reuse of components?

Answer: If the demand for air flow increases, then you will likely need a new system. Oversizing would make sense if you don't want to uninstall everything. Ducts would need to be uninstalled very carefully to prevent any damages and this is not in practice today.

Culturally, businesses are slow to make changes.

Question 5: If we want to start the practice of reuse, which parties could have the greatest role in executing this?

Answer: regulations

Participant 5

Industry: HVAC Manufacturing
Position: Director of sustainability and external regulations

Question 1: Is designing for reuse being considered on the manufacturing side? Is adaptive reuse?

Answer: Yes, customers are very interested and we are eager to develop a business model within the year. The company is looking at the products that are existing in huge numbers, like diffusers and AHUs.

Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?

Answer: Essentially everything. From our company, it would be diffusers and AHUS.

The challenge with diffusers is that they come in high volumes, so there needs to be enough "second-hand" supply to make it worth it. It is also tricky to put value back into a small component like diffusers.

An AHU is a large component that can be refurbished, by replacing fans and other electronic components. This would add value back into the component and the supplier could sell it for nearly the same price as a new one.

The challenge with AHUs is that their performance is crucial and refurbished units would still need to meet update performance regulations. AHUs are currently designed (since the 1990s) that parts within the system can be replaced. However, it needs to be investigated further so that materials can be disassembled.

Chillers also have the potential to decrease the embodied carbon heavily.

Question 3: What steps do you feel would promote the reuse of existing components? Do you feel like current components could be reused or would you have to specifically design for it?

Answer: Regulations that would somehow promote the reuse of HVAC components. The challenge is meeting the performance regulations (efficiencies, energy usage, and air velocities). If regulations could somehow make it easier for manufacturers, then it could make the process easier. The embodied carbon needs to be balanced with the operational.

There needs to be sufficient space to store the components, as well as enough space to scale up the inventory.

A successful business model needs to be established. It is unclear if they supplier should take back the components for free. Or if the builder owner pays a small fee to have them removed from their site.

Distance from the site also needs to be taken into account. The components need to be cleaned and their functionality needs to be checked. All electronic components need to be replaced.

Bottom-line – the solution needs to be easy and it needs to be better than just using recycled steel.

Question 4: What kind of barriers or challenges do you feel would prevent the reuse of components?

Answer: One of the biggest barriers that we have now is in reality we cannot really reuse. Because it really doesn't comply with the current building regulations and needs to be solved. We have to deviate a bit but it shouldn't be so much. Complying with regulations could include efficiencies, product performance, air velocities, and energy use. We

can adapt the products to some extend but we cannot fulfil it 100% since the product might be produced 10 years ago and designed to fulfil the demand at that time but now regulations have evolved and they are stricter. If it's not profitable or if CO2 neutral steel takes off, then the idea of reusing could become obsolete. The problem is the word "second-hand." It would mean that the product is cheaper. However, that may not be in the supplier's best interest. The supplier would refurbish it so its performance is that of a completely new one. The idea of reuse also changes country to country and even within companies. Some people don't have the same mindset or optimism about reuse. The market needs to scale up to meet the demand and product quantities that building owners are asking for.
Question 5: If we want to start the practice of reuse, which parties could have the greatest role in executing this?
Answer: The markets need to be moving in parallel. The suppliers need to scale up enough to have the inventory while the demand needs to be present for it to be profitable, and the government needs to provide regulations to guide all the parties. The goals of the customers also need to be aligned. For example, if the customer just wants to buy the most economical option, then buying completely new will be in their interest (given that the refurbished product is nealy the same price as the new). However, if the client is trying to achieve a climate agenda, then they will want the second hand option. Big investors and real state owners are the biggest drivers – companies with less volume or private owners don't have the incentives yet**.**

Participant 6

Industry: Building Regulations and Planning **Position:** Sustainability Expert
Question 1: Are building regulatory agencies considering the reuse of HVAC components in its regulations?
Answer: yes, we are looking into how circularity can be pushed into the building regulations.
Question 2: What kind of barriers do you think would prevent reuse?
Answer: Regulations prevent the reuse and construction of dangerous materials. Asbestos and chromium 6 need to be considered. SPF and technical side need to be taken into account as well.
Question 3: What kind of drivers could regulations introduce to promote reuse?
Answer: Climate declaration is a driver. T
Question 4: Do you think regulations could help provide financial incentives to building owners or manufacturers?
Answer: Perhaps we could make regulations that are more "forgiving" to renovations of a certain size. We are currently rewriting the building regulations and looking where the new regulations are hindering innovations. Looking at different business models to see what would make it profitable. Perhaps building owners could "rent" the system. Ideally, BBR could write regulations on how to build – promoting the idea of reuse and could make deconstruction cheaper. Perhaps this needs to be done by green building certifications. Overall, the construction industry needs to have a more holistic view.
Question 5: What kind of barriers or challenges do you feel would prevent the reuse of components?
Answer: Financially, there needs to be a balance between the price of new and old. The price of old cannot exceed price of new.

Participant 7

Industry: HVAC Manufacturing **Position:** Director of sustainability and external regulations
Question 1: Is designing for reuse being considered on the manufacturing side? Is adaptive reuse?
Answer: At the moment there is very little interest. Perhaps more common with AHUs. There is more activity in The Netherlands. But this is a change we have to do in the future.
Question 2: What kind of HVAC components do you feel have the greatest potential for reuse?
Answer: Air ducts and AHUS. Material and plastics are materials ideal for reuse. Ducts look the same over the years but you may have to change the sealants. The simpler the product, the better for reuse – this will increase the likelihood of being reused. The steel casing of an AHU can be reused. We have upgraded the corrosion class from some of our AHU casings from C4 to C5. Reusing AHUs depends on how old it is. If it is really old, the shell can be reused but the electrical components will have to be replaced, the motor for example. The heat exchanger can last a while, as long as the filters are changed

regularly. Dirt can deteriorate the heat exchanger. Building owners are more diligent about changing filters as there is more awareness for good indoor air quality.
Question 3: What steps do you feel would promote the reuse of existing components? Do you feel like current components could be reused or would you have to specifically design for it?
Answer: When we design, we try to make it easier for our products to be fixed. Maintaining the equipment will enhance its longevity.
Question 4: What kind of barriers or challenges do you feel would prevent the reuse of components?
Answer: Governmental… more standardization on building and reusing. If not globally, then for each country. Every country does things differently. For example, some countries prefer square ducts and some prefer circular. Economical…in the short term, it has to be subsidised like greenest innovations. There could be high costs for the time it requires to reuse the material (i.e. disassembling, cleaning), and costs from transportation, storage and technical experts. Technical…The standards can make it difficult to reuse, for example trying to meet certain energy efficiencies. An AHU may look the same in 30 years but the technical parts by be different. Innovation could prevent reuse and manufacturers want to have the fancies products. Culturally, countries have different resources to implement practices like this. And this can influence whether or not the investments are there to incentivise it. Hopefully people realise this is what we need to do.
Question 5: If we want to start the practice of reuse, which parties could have the greatest role in executing this?
Answer: A new business model, and new businesses in general, are needed. Incentives need to be established, primarily by the government, to create a market. Most companies are trying to develop a business model for this. Everyone would have to be doing this together and at the same pace for it to work. There would have to be the right amount of investing, enough but not too much.

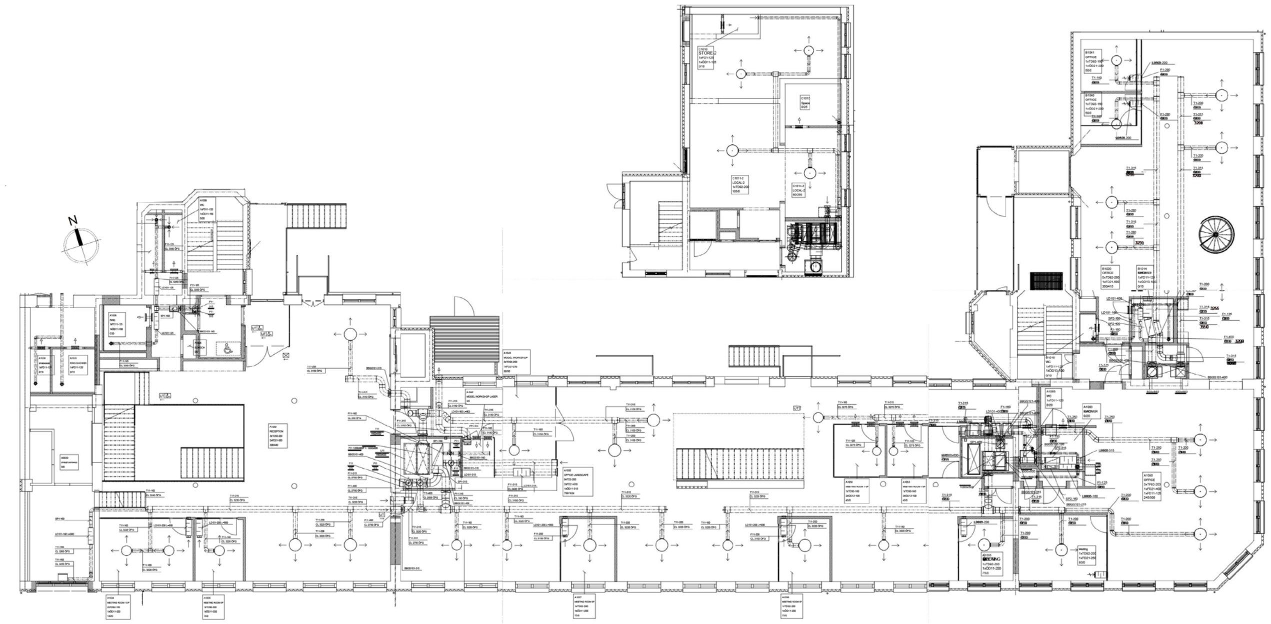
Participant 8

Industry: Sustainability services **Position:** Head of the market development
Question 1: Do you think reuse HVAC components is feasible or should it be considered?
Answer: When it comes to climate declaration and carbon budget, what we do is tracking all phase of building CO_2 emission. If we could manage to reuse ducts we can reduce significant amount of emission since installation is contributed high share of building carbon emission. So instead of changing doors or windows, we can reuse components and aim for higher carbon savings.
Question 3: What kind of barriers or challenges do you feel would prevent the reuse of components?
Answer: Manufacturers are slower compared to other sectors that our company has worked with, they are not at the forefront and more or less waiting for somebody to put the requirements. There is uncertainty if they know the climate impact of their products due to the lack of EPDs. One of the reasons could be the lack of force or incentives for manufacturers to start off this business. One of the barriers here is that even upcoming climate declaration regulation d not specify the reduction amount that needs to be achieved or target values. It seems that the lack of business models and uncertainties about whether it should be started or not, extra cost of workmanship, rent, etc., has always existed with the practice of reusing other products. The company where I have worked with before had come up with the idea of reusing the ceiling and the logistics and business model involved. Today it works, not only here but in other countries also. They couldn't say from the beginning if it would work or not but they wanted the reuse market so they had to take back the systems. If you look at ventilation ducts, it is not the same, but it is also more straightforward than ceiling. Our product does not have enough product specific data in our platform about HVAC components and it is mostly generic data. This affects the final result of total carbon emissions in the building as installation products are at a great scale of carbon emissions of the building. Also, in our platform, there are not many options to compare the impact between HVAC components and other products to choose the best one for a project.
Question 4: If we want to start the practice of reuse, which parties could have the greatest role in executing this?
Answer: It needs to be more education and knowledge within the company to educate the employees on how reuse could be done. The sales process should change to, there should be a strong relationship with the subcontractors. They should work closely with the contractors to facilitate reuse. There should be a change in product design so that they could be dissembled more easily. Here in Sweden there should be a better interaction between manufactures, technical consultant, sustainability consultants, architects, and main/ sub-contractors to facilitate this. Recently, a company has included the HVAC system in its climate declaration but not with reusing them and still there is a lack of pilot projects.

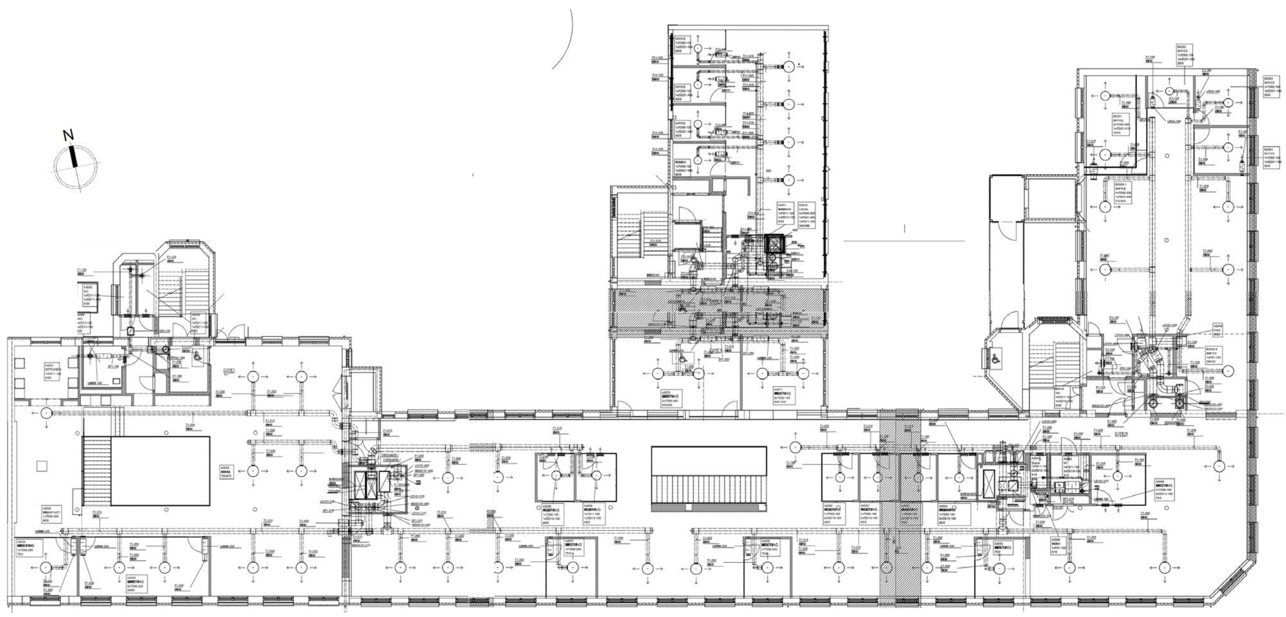
Appendix E

Existing Office Ventilation Design

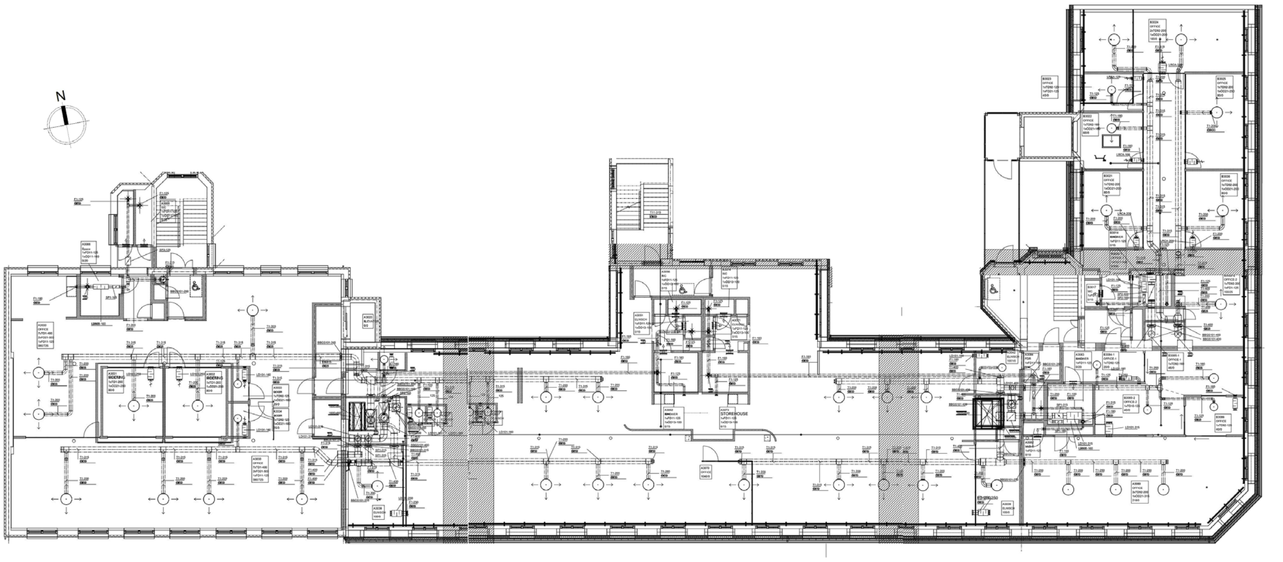
Floor 1



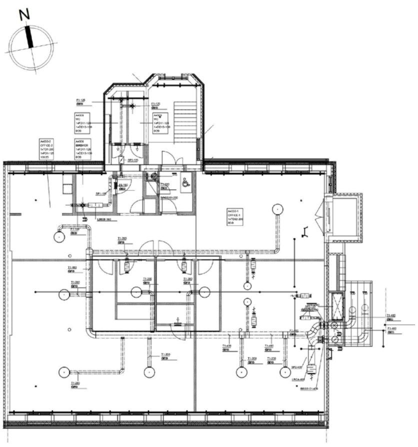
Floor 2



Floor 3

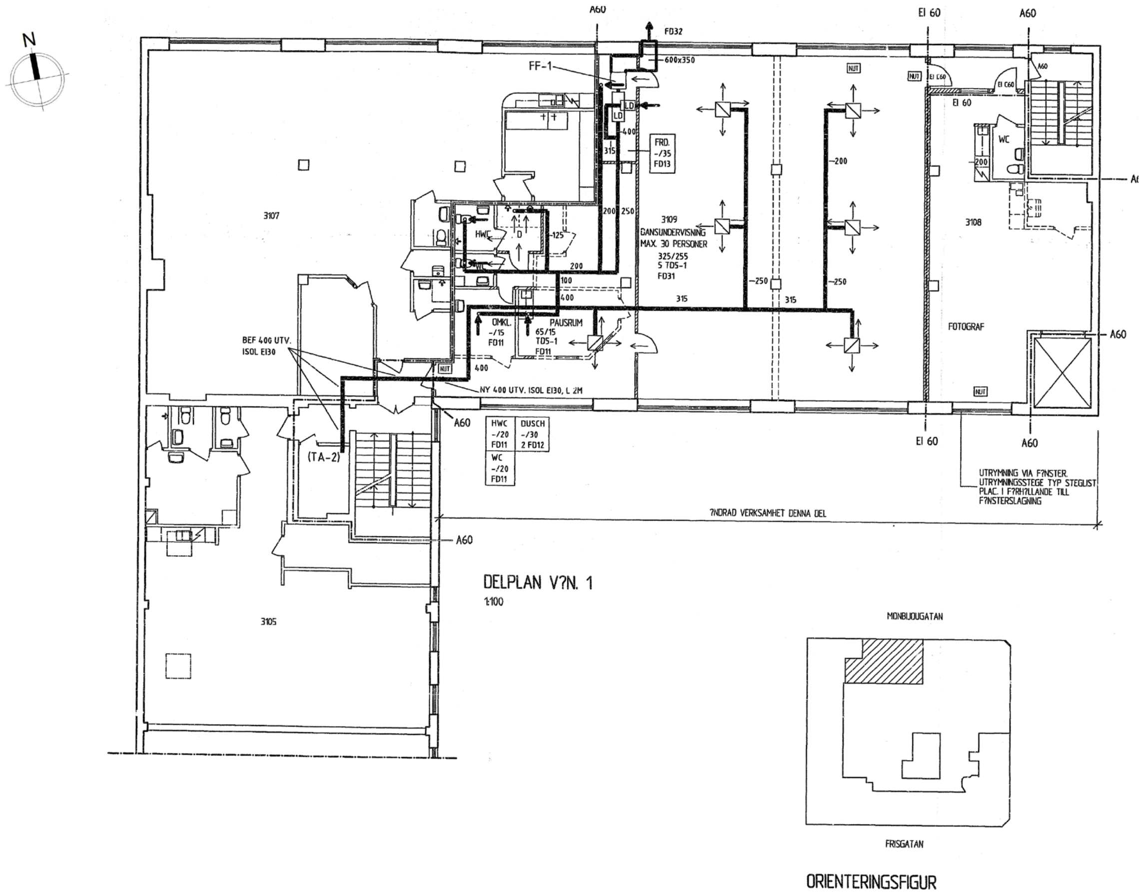


Floor 4



Appendix F

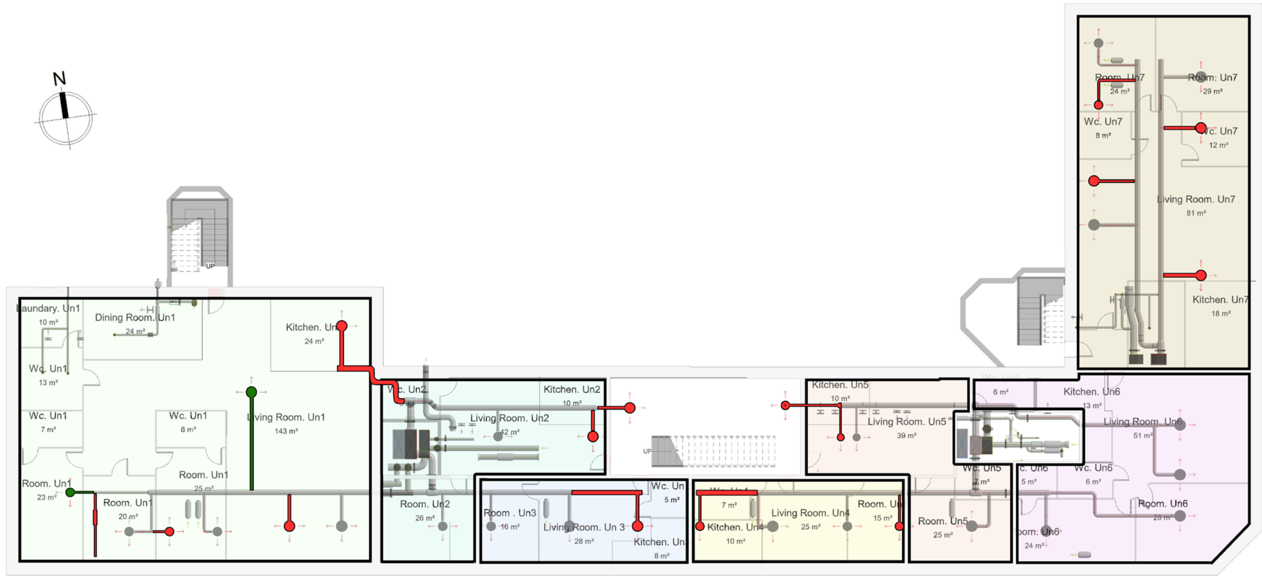
Dance Studio Ventilation Design



Appendix G

Apartment ventilation design

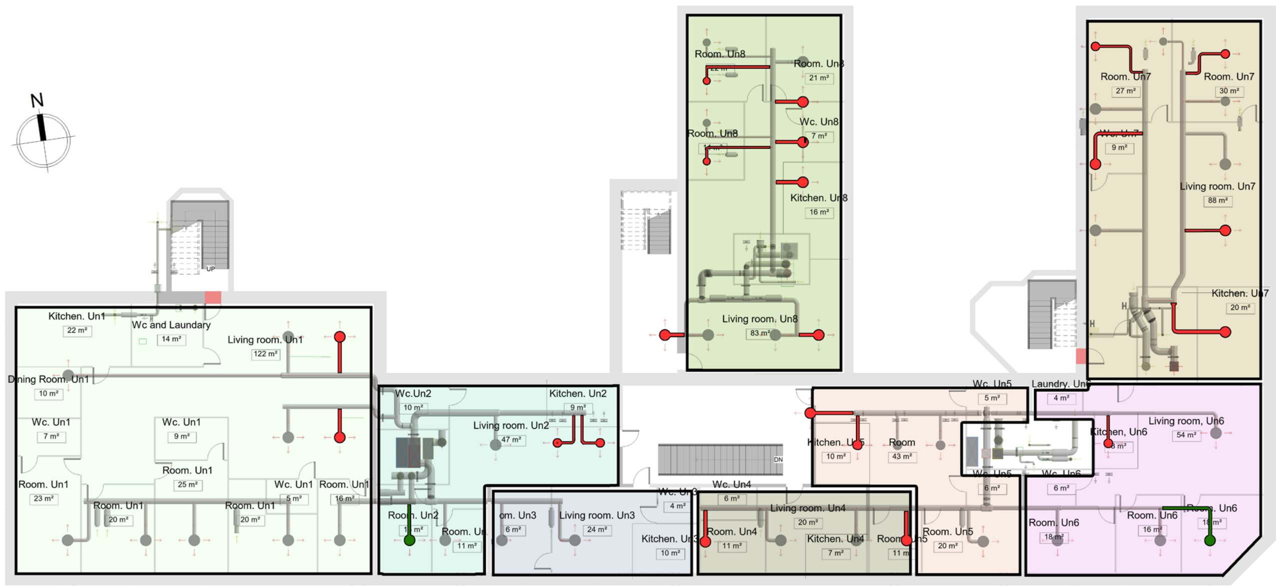
Floor 1



Unit 1 Unit 3 Unit 5 Unit 7 Unneccessary Ducts

Unit 2 Unit 4 Unit 6 Needed Ducts

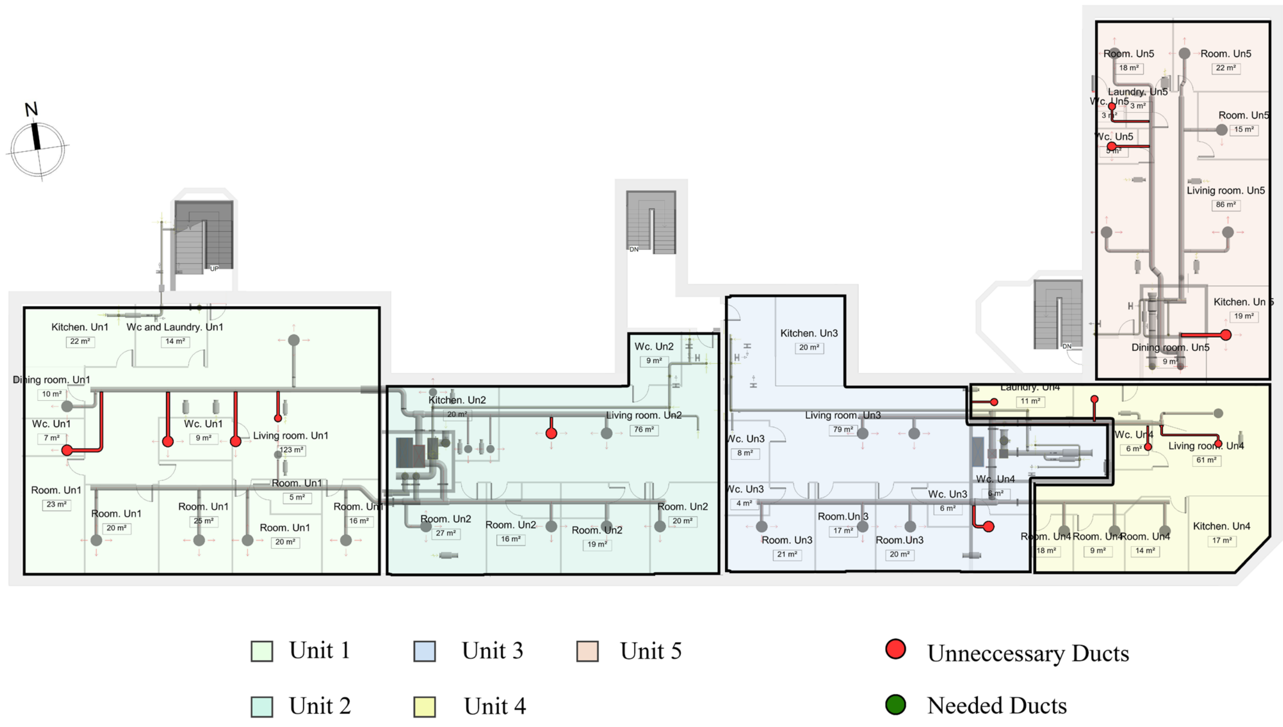
Floor 2



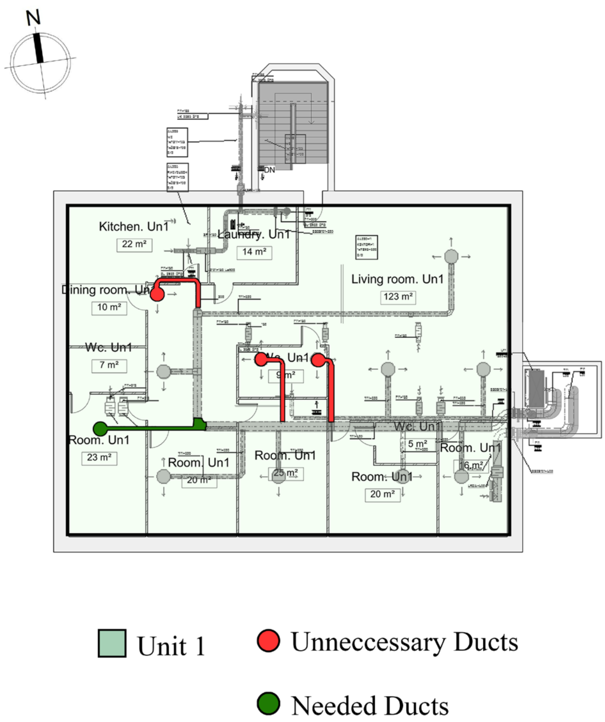
Unit 1 Unit 3 Unit 5 Unit 7 Unneccessary Ducts

Unit 2 Unit 4 Unit 6 Unit 8 Needed Ducts

Floor 3



Floor 4



Appendix H

GWP Impact Results

	Total GWP / kg CO_2 eq.				
	A1-A3	A4	A5	B2	C1-C4
Office Base Case	1,38e+04	9,08e+01	2,13e+02	0,00e+00	8,30e+00
Office Historic Adaptive Reuse	1,32e+04	8,93e+01	2,08e+02	1,33e+01	6,50e-02
Apartment Base Case	1,03e+04	2,88e+01	2,02e+02	0,00e+00	3,85+02
Apartment Future Adaptive Reuse (fixed)	0,00e+00	0,00e+00	0,00e+00	3,52e+00	1,75+01
Apartment Future Adaptive Reuse (full dis.)	0,00e+00	0,00e+00	0,00e+00	5,75e+01	1,75+01

Generic data- One Click LCA, Sweden: GWP impact per 1 kg of duct

	Total GWP / kg CO_2 eq.				
	A1-A3	A4	A5	C2	C1-C4
Ducts	3,88E+00	1,02E-02	3,93E-02	3,83E-02	2,18E-03

Specific data – Swedish: GWP impact per 0.675 kg/unit of fittings

	Total GWP / kg CO_2 eq.				
	A1-A3	A4	A5	C2	C1-C4
Fittings	2,37E+00	4,18E-02	1,02E-02	6,14E-03	8,87E-02

Appendix I

Components	Reference Service Life / years
Duct	50
Diffuser	25
Fitting	50
Silencer	25
AHU	25
Duct insulation	As building
VAVs	25
Ventilation grills	60
Overflow unit-Sound absorber-Outdoor air hood	25

Appendix J

Apartment design air flows

	Total area / m^2	Living Room / m^2	Min. air flow / l/s	Room 1 / m^2	Min. air flow / l/s	Room 2 / m^2	Min. air flow / l/s	Room 3 / m^2	Min. air flow / l/s	Room 4 / m^2	Min. air flow / l/s	Room 5 / m^2	Min. air flow / l/s	Total supply / l/s
Floor 1														
Unit 1	236	143	50.05	25	8.75	20	7	23	8.05					73.85
Unit 2	86	42	14.7	26	9.1	16	5.6							29.4
Unit 3	57	28	9.8	16	5.6									15.4
Unit 4	57	25	8.75	15	5.25									14
Unit 5	87	39	13.65	25	8.75									22.4
Unit 6	125	51	17.85	26	9.1	24	8.4							35.35
Unit 7	168	79	27.65	23	8.05	29	10.15							45.85
Floor 2														
Unit 1	217	118	41.3	25	8.75	20	7	23	8.05	20	7			72.1
Unit 2	92	47	16.45	11	3.85	15	5.25							25.55
Unit 3	59	24	8.4	16	5.6									14
Unit 4	44	20	7	11	3.85									10.85
Unit 5	70	43	15.05	11	3.85	20	7							25.9
Unit 6	104	54	18.9	18	6.3	16	5.6	18	6.3					37.1
Unit 7	152	92	32.2	30	10.5	29	10.15							52.85
Floor 3														
Unit 1	226	133	46.55	23	8.05	20	7	25	8.75	20	7	16	5.6	82.95
Unit 2	151	76	26.6	27	9.45	16	5.6	19	6.65	20	7			55.3
Unit 3	144	79	27.65	21	7.35	17	5.95	20	7					47.95
Unit 4	110	61	21.35	17	5.95	14	4.9	9	3.15	18	6.3			41.65
Unit 5	163	90	31.5	19	6.65	22	7.7	15	5.25					51.1
Floor 4														
Unit 1	226	133	46.55	23	8.05	20	7	25	8.75	20	7	16	5.6	82.95

Appendix K

Challenges of reuse

Governmental	Technical
• Ongoing changes in regulations • Difficult to repurpose old systems to perform up to today's standards • Lack of guidelines on what or how to reuse • Lack of infrastructure	• It is situational and not applied for all cases • It might not outweigh the benefit of installing a new system • Lack of knowledge • Risk of leakage, regarding air ducts • Ducts are bulky and difficult to store • Electrical products like pumps, heat exchangers, fans, and heating coils pose challenges in reusing due to loss of efficiency over time. • No clear information on age & condition of existing equipment • Hard to warranty reused or refurbished components. • Risk of equipment failure is higher with older equipment, • Lack of an integrated design approach across the various disciplines. • Possible need for more maintenance • No pilot projects or proof of success
Financial	**Environmental**
• The low price of a reused product would not benefit the supplier. • Services involved with reuse could be higher than buying new. • Lack of business models	• Presence of toxic materials could prevent reuse. • The CO_2 emissions from reuse services could be higher than the emissions from using new materials.

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