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Climate impact from HVAC systems in the production and construction phase

A case study of two university buildings in Sweden

Master's thesis in Industrial Ecology

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Abstract

As of today, the magnitude of the climate impact of the HVAC systems is currently uncertain as few detailed studies have been made on the subject. This study therefore intends to increase the knowledge regarding the climate impact of HVAC systems by calculating the climate impact of two university buildings in Sweden for life cycle phases A1-A5.1 and comparing the results to existing reference values.

The results of the climate impact calculations are that the climate impact of Umeå Building is 30 $kgCO_2e/m^2_{Atemp}$, and Nya Konst is 31 $kgCO_2e/m^2_{Atemp}$. The result of the calculation of Umeå Building is based on Construction documents which makes for a sturdier foundation of the results while the result of Nya Konst is based on Project planning documents, that had less information available in them which makes the result more uncertain.

The results also show that without a reference building to draw assumptions from when calculating the HVAC system with Project planning documents, it can be hard to achieve a high enough coverage rate to have a solid result.

A hotspot analysis shows that by only calculating the six product groups with the largest climate impact for Umeå Building it would correspond to 81% of the total impact from the HVAC system and the calculations would be much quicker. The product groups not calculated could for example be accounted for with an add-on or by coverage rate.

Several issues with performing this type of calculations are identified, such as the current lack of EPD´s, difficulties in processing the data provided through BIM-models and the time-consuming work of locating weights and material content for the products. It is therefore suggested that it would be preferable to update the BIM-models to include weight and material content of the HVAC products. This would make the calculations easier and faster to carry out. If also the availability of EPD´s increased, it would also be possible to increase the certainty of the results.

Key words: Life cycle assessment (LCA); building; technical installations; heating, ventilation and air conditioning (HVAC)

Klimatpåverkan från VVS-installationer i byggskedet

En fallstudie av två universitetsbyggnader i Sverige

Examensarbete inom masterprogrammet Industrial Ecology

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Sammanfattning

Det råder för tillfället stor osäkerhet kring hur stor klimatpåverkan av VVS-installationer är vid uppförandet av byggnader då det endast gjorts få studier för att undersöka detta. Syftet med detta arbete är därför att bidra till kunskapen om hur stora utsläppen kopplade till VVS-installationerna är genom att beräkna klimatpåverkan av VVS-installationerna i två byggnader för livscykelstadierna A1-A5.1 och sedan jämföra detta med de referensvärden som finns.

Resultatet visar att klimatpåverkan för Umeå Building är 30 $kgCO_2e/m^2_{Atemp}$, och för Nya Konst är den 31 $kgCO_2e/m^2_{Atemp}$. Då beräkningen av Umeå Building är baserad på bygghandlingar är dess resultat mer underbyggt medan resultatet för Nya Konst är mer osäkert då de systemhandlingar som beräkningen är baserad på innehöll mindre information än bygghandlingarna.

Resultatet visar också att det vid beräkning av klimatpåverkan av VVS-installationerna, med systemhandlingar som underlag, kan bli svårt att uppnå en tillräckligt hög täckningsgrad för ett säkert resultat utan en referensbyggnad att basera antaganden på.

Hotspot-analysen visar att genom att bara beräkna de sex produktkategorierna med störst klimatavtryck skulle 81% av klimatpåverkan för VVS-installationerna i Umeå Building täckas in och detta skulle kunna vara ett potentiellt sätt att förenkla klimatberäkningen, vilket skulle spara tid. De resterande produktkategorierna skulle förslagsvis kunna täckas in med en form av påslag eller en täckningsgrad.

Det identifieras även flera svårigheter med att utföra själva arbetet, så som litet utbud av EPD:er, svårhanterliga data från modellerna och det tidskrävande arbetet med att hitta vikt och material-innehåll för produkterna. Arbetet med att hitta vikt och material-innehåll hade kunnat underlättas av att denna information förslagsvis finns tillgänglig i de modeller och dokument som används som underlag till beräkningarna. Detta skulle framförallt snabba på processen att beräkna klimatpåverkan av VVS-installationer på det här sättet. Om även utbudet på EPD:er utvidgas skulle det också leda till att kunna beräkna resultat med högre säkerhet.

Nyckelord: Livscykelanalys (LCA); byggnad; tekniska installationer; VVS-installationer

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CONTENTS

Acronyms

HVAC systems	Heating, ventilation, air-conditioning systems.
GHG	Greenhouse gas
EF	Emission factor
BoM-list	Bill of Materials-list
CO_2	Carbon dioxide
SH	Sanitation and Heating (Building part 84)
CV	Cooling and Ventilation (Building part 85)

Glossary

Technical description = Contains detailed descriptions of the different products and components of the system.

A_{temp} = The area that has a regulated temperature over 10 degrees for all stories, the attic and the cellar of a building, and that is limited by the building´s envelope (Malmqvist et al., 2023). Included in this is also the area that is taken up of inner walls, shafts and alike.

BTA = The sum of all areas of all floors limited by the building´s outside (Malmqvist et al., 2023).

CO_2e = Carbon dioxide equivalents, a unit for measuring the aggregated climate impact of different greenhouse gases (Malmqvist et al., 2023).

EN 15804 = European standard for calculating environmental product declarations (Malmqvist et al., 2023).

EN 15978 = European standard for calculating the environmental impact of buildings (Malmqvist et al., 2023).

EPD = Environmental product declaration, measures the emissions of a product during its lifetime, follows EN 15804 (Malmqvist et al., 2023).

GWP = Global Warming Potential, a measure of the potential contribution to the greenhouse effect from different greenhouse gases over 100 years (Malmqvist et al., 2023).

1 Introduction

With the climate crisis as a driving force the building sector is focusing on contributing to combat climate change (Energy Agency & Nations Environment Programme, 2020). The building sector in fact stands for 21% of the total GHG emissions in Sweden which does not include GHG emissions happening abroad due to the consumption of the building sector (Boverket, 2023a).

In 2022 a law on mandatory climate declaration of buildings came into effect in Sweden to show the climate impact of buildings (Boverket, 2021). The life cycle of a building is divided into three phases: phase A which is the production and construction phase, phase B which is the use-phase, and phase C which is the end-of-life phase, and an optional phase D which includes the reuse- recovery- and recycling-potential (Moncaster & Symons, 2013). The climate declaration should contain information and accounting about the climate impact (from emissions of GHG) for the production and construction phase, A1-A5 (Boverket, 2021). The lifecycle phases are named according to the European standard EN 15978. The life cycle of a building is further described in Section 2.2.

Currently, HVAC systems are not included in the mandatory climate impact calculation in the climate declaration law (Boverket, 2022f). As of now it is only the load-bearing structure of the building, the interior walls and the buildings envelope that is included in the climate declaration. With new national targets set in Sweden the building sector has to continuously reduce their GHG emissions and are now moving from mostly looking at the foundations and structural frame to looking at more parts of the building (Stigemyr Hill & Borgström, 2022). The industry is showing a spike in interest in more thorough values for their GHG emissions regarding heating, ventilation, and air conditioning systems (HVAC systems), not only during the use-phase but also during the construction phase. That GHG emissions from HVAC systems during A1-A5 has long been overshadowed can be illustrated by the Swedish climate database Boverket (2022) that has no data regarding the climate impact from HVAC products for the A1-A5 phases.

Few detailed studies have been made on the climate impact of HVAC systems and how large the GHG emissions connected to A1-A5 are for HVAC systems is currently uncertain. Some previous studies are described in Section 1.5. A reference value study was made by Malmqvist et al. (2021) to investigate the climate impact of the construction of different types of buildings. The study presents reference values which indicate the climate impact of the HVAC systems for the different types of buildings. The study showed that the climate impact of the HVAC systems can vary a lot from building to building and by building type. IVL Svenska Miljöinstitutet (2022a) also uses the reference values in the report by Malmqvist et al. (2021) with a 25% add on as generic values for estimations of the HVAC systems climate impact based on a buildings A_{temp}.

During the progress of this report, an updated version of the reference value study was published which contained separate reference values for the subcategories of the HVAC system (Malmqvist et al., 2023). In the new version of the report the values for the

HVAC system for the different building types were updated and several of the reference values were increased, for example the value for a school more than doubled. This further goes to show the uncertainty regarding the climate impact from HVAC systems.

The use of reference values has been a good start to evaluating the extent of which HVAC systems contribute to the climate impact of buildings. However, for more accurate and detailed analysis of climate impact accounting and mitigation, there is a need for more studies. This study therefore aims to add to the existing knowledge of the climate impact of HVAC systems. The study will do so by analyzing two buildings provided by Akademiska Hus, "New building for Umeå university" in Umeå and Nya Konst in Gothenburg. Akademiska Hus is a Swedish real estate business for universities (Akademiska Hus, 2023d). They are one of the largest real estate companies in Sweden and are state owned. They also aim to build sustainably and lower the climate impact of their buildings (Akademiska Hus, 2023e). The buildings are described more in Section 1.4.

1.1 Aim and research questions

The aim of the report is to analyze the climate impact of HVAC systems in two different buildings during life-cycle phases A1-A5.1. The report will do so by answering the following research questions:

- What is the calculated climate impact from HVAC systems during A1-A5.1 for the two buildings?
- How does the calculated climate impact compare to reference values?
- What are the hotspots for climate impact and what is the potential to lower the climate impact from the HVAC systems?
- What are the differences in calculating the climate impact with Project planning documents compared to Construction documents? What is needed to calculate the climate impact using Project planning documents?

1.2 Limitations

This report is limited to studying the climate impact from lifecycle phases A1 to A5.1 in the production and construction phase and will thereby not study the phases A5.2-A5.5, B, C and D. The report is also limited to the two studied buildings and their properties. The quantities of the products in these buildings are provided by Akademiska Hus and to calculate the impact it is assumed that these quantities are correct. The report is further limited by the available data, when generic data and EPD's are not available the climate impact will be based on the material content of the products. The report will only study the Sanitation and heating (SH) system and the Cooling and ventilation (CV) system of the buildings, other parts of the HVAC system will be excluded. For the study of Nya Konst in Gothenburg the entire building will not be examined. Only the part named Kuben is studied for this report, and the report also had to exclude the technical room for heating, cooling and domestic water connected to Kuben due to lack of information.

1.3 Societal, ethical and ecological aspects

For societal and ecological aspects, it is deemed to be that the knowledge regarding HVAC systems and their climate footprint can be used to in turn reduce the GHG emissions. If this knowledge leads to reduced GHG emissions, it could also lead to reduced costs for coping with the damages from climate change. Another ecological aspect could be that the report helps bring knowledge about how to reduce the climate impact from HVAC systems during A1-A5.1. The report had no ethical aspects to take into consideration as Akademiska Hus did not need any sensitive data anonymized.

1.4 Description of studied buildings

The owner of both buildings is Akademiska Hus and it is also they who have provided the information regarding the HVAC systems of the buildings. Akademiska Hus is one of Sweden's largest property companies who strives towards developing and managing university and college buildings (Akademiska Hus, 2023a). Akademiska Hus is a state-owned company. In Section 1.4.1 and 1.4.2 each building is described briefly.

1.4.1 New building for Umeå university

“New building for Umeå university” (from now on called Umeå Building), located in Umeå, is a university building and will mostly consist of exam rooms that will be able to be used even when no exams are taking place (Akademiska Hus, 2021). The HVAC systems will thus be designed to cope with many students in the same room at the same time. The building will have an A_{temp} of 8,616 m^2 and an image of the building can be seen in Figure 1.

Figure 1
Image of Umeå Building.

Note. Image by LINK Arkitektur.

1.4.2 Nya Konst

Nya Konst is a university building dedicated for the Faculty of Fine, Applied and Performing Arts located in central Gothenburg (Akademiska Hus, 2023f). The building will thus have many kinds of facilities for teaching, including lecture halls, music halls, offices and painting rooms etc. (Akademiska Hus, 2023c). The HVAC systems will thereby have to be shaped in preference for each room's specific requirements. The part of Nya Konst that is studied (Kuben) will have an A_{temp} of 15,423 m^2 and an image of the building can be seen in Figure 2.

Figure 2

Image of Nya Konst.

Note. Image by Tham & Videgård Arkitekter.

1.5 Previous studies

In an article by Ylmén et al. (2019) different life cycle stages of an office building were examined. The life cycle stages examined were A1-A5 + B4 +B6 + C1-C4 according to EN 15804. This study examined multiple environmental impacts related to the life cycle of the building and the different parts of the building. Among the results of this report were that due to lack of data it was difficult to evaluate the impact of the HVAC system. But the results also showed that the materials used in the HVAC system can have a significant environmental impact related to them in several impact categories.

A study by Kiamili et al. (2020) investigated the requirements and developed method to be able to do a detailed LCA of the HVAC systems based in BIM. The system boundaries of the study were life cycle phases A1-A3 + B4 + C3-C4. The results from the study showed the HVAC systems had a much higher amount of embodied carbon than the target values that it was compared to. The study was however performed on an office building in Switzerland with different preconditions from a building in Sweden. This study was based on a master thesis carried out by Kiamili (2020) with the same results.

There has also been a thesis carried out with Bengt Dahlgren with the aim of calculating the climate impact of the HVAC system of apartment buildings (Lappalainen, 2021). This study was limited to life cycle phases A1-A3. Among the results of the thesis were that it´s currently very difficult to provide an answer to how large the impact of HVAC systems in apartment buildings is due to uncertainty in available data

A report financed by SBUF and NCC analyzed two office buildings and two apartment buildings to establish key figures for the climate impact of electrical installations, cooling and ventilation, sanitation and heating, sprinklers and elevators for the two building-types, for life cycle phases A1-A3 (Enebjörk et al., 2022). The results of the study were that in total the installations stand for about 8% of the total climate impact of materials in apartment buildings and up to 20% of the total impact from materials in office buildings.

Lastly there has been a study carried out by Calderon et al. (2022) on Hoppet, a pre-school in Gothenburg. This study was very ambitious and strived to include all of the GHG emissions from the HVAC installations for the life cycle phases A1-A5 according to EN 15978 when calculating the climate impact of the preschool. The results of the calculations of the HVAC system in Hoppet were that the calculated impact was above the reference values, which indicate that there is a need for further studies on the climate impact of HVAC systems to get a better knowledge on how the climate impact of different HVAC systems can vary.

2 Theory

This part of the report will provide some theoretical concepts related to the climate impact of buildings and the methodology of the report, such as life cycle assessments (LCA) in general and on buildings in particular. It will also provide a brief theory about the methodology for calculating the climate impact of buildings. The categorization systems used in the report will also be explained along with the different document types mentioned in the report.

2.1 Life cycle assessment (LCA)

An LCA is a tool to estimate all the emissions for a predefined object throughout the entire life-cycle of the object (Hauschild et al., 2018). This can enable comparisons between different products, systems or materials to identify the best available choice to reduce emissions. A full LCA can also cover many different impact categories, In EN 15804 the mandatory categories are Global Warming Potential (GWP), Eutrophication Potential (EP) and Acidification Potential (AP) stratospheric ozone depletion potential (ODP) and photochemical oxidants creation potential (POCP), but it can also focus on one specific impact category (Ylmén et al., 2019). An LCA can cover either all the steps from material extraction to the end-of-life treatment (Cradle to grave), or it can be shortened to end at where the product leaves a specific factory (Cradle to gate) (Baumann & Tillman, 2003).

2.2 Life cycle assessment of buildings

As of today, it is not common to perform an LCA of a building in the earlier stages of designing a building (Hauschild et al., 2018). This means that when an LCA is performed most of the choices that could have an impact on the climate impact of the building are already made. Therefore, there is a consensus in the sector to move towards using LCA in earlier phases of the building design to be able to find alternative designs for the buildings. The different stages of the life cycle of a building are presented in Figure 3.

Figure 3

Life cycle stages according to EN 15978 (Boverket, 2021b).

Building life cycle information				Added information
A1-A5 Construction stage				**D Benefits and loads beyond system boundary**
A1-A3 Product stage	**A4-A5 Construction process stage**	**B1-B7 Use stage**	**C1-C4 End of life stage**	
A1 Raw material extraction	A4 Transport	B1 Use stage	C1 De-construction, demolision	
A2 Transport	A5 Construction process	B2 Maintainance	C2 Transport	
A3 Manufacturing		B3 Repair	C3 Waste processing	
		B4 Replacement	C4 Disposal	
		B5 Refurbishment		
		B6 Operational energy use		
		B7 Operational water use		

Note. Authors own translations.

When assessing the climate impact from HVAC systems in buildings it has been common to look mostly at making the systems more energy efficient, in order to reduce the energy consumption, or transferring from fossil-based energy resources to renewable energy (Kiamili et al., 2020). When buildings become more and more energy efficient, the embodied carbon from the HVAC systems takes up a larger share of the total GHG emissions from the HVAC systems. Despite this there have not been many LCAs carried out which have taken HVAC systems into account for the A1-A5 phases (Kiamili et al., 2020).

2.3 LCA data for buildings

To calculate the climate impact of the HVAC systems in the buildings, three types of data were used: Specific data, Generic data, and Material content. These types of data and where to find them are described below.

2.3.1 Specific data

The specific data are provided in Environmental Product Declarations (EPD) and include the specific environmental impact data for a specific product, e.g., one type of ventilation duct (Malmqvist et al., 2023). These EPDs can be found in both databases that collect EPD’s in general, and from the manufacturers themselves.

2.3.2 Generic data

Generic data include a general environmental impact for a representative type of product, e.g., an air exchanger with heat recovery (Malmqvist et al., 2023). These types of data are found in databases where the climate impact factor is provided with a conservative value and a typical value (Boverket, 2023b). The conservative value has an add on of 20-25% (varies for different databases). The add on is used when calculating the GHG emissions for the Swedish climate declaration to make sure the emission factor is larger for generic data than for EPDs and thereby provide an incentive for using EPDs. This report used the typical value for the climate impact factor when using generic data.

2.3.3 Material content data

Data on the climate impact factor of the material content is gathered from databases. The material data comes from Ecoinvent v3.8 where many types of raw material can be found together with multiple impact categories and climate impact methods. This report also included material data found in generic data databases as material content.

2.4 Climate impact calculations according to the climate declaration

As stated earlier it is now mandatory to calculate the climate impact of new buildings in Sweden, with some exceptions. The climate declaration does not follow the EN 15978 standard completely as it is only mandatory to calculate life-cycle phases A1 to A5 (Boverket, 2021b).

In the climate declaration, the climate impact of a building is calculated as the combined effect of GHG emissions of greenhouse gases, measured in GWP-GHG (Boverket, 2022a). This excludes the uptake and GHG emissions of biogenic coal. The formula from Boverket (2022b) for calculating the climate impact is presented in equation (1).

Equation (1)
Calculation of climate impact.

$$\text{Climate impact [kgCO}_2\text{e] = Resource [kg] x Climate data [kgCO}_2\text{e/kg]}$$

The first type of data required for the climate impact calculation (equation (1)) is information on the resources needed for the construction of the building (Boverket, 2022c). The resources are the products and energy used in the construction of the building. The data on the number of products and amount of energy used is summarized in a compilation.

The second type of data needed in the calculations is climate data which is the measure of the climate impact of the resource, in the unit $kgCO_2e$ per functional unit of resource (Boverket, 2022a). The functional unit of resource can be kg, kWh, MJ or m^2 for example. The types of climate data are explained in Section 2.3, however it is only specific data and generic data from Boverket that is accepted for the climate declaration.

Each resource is multiplied with its individual climate data to calculate the climate impact for every individual resource used (Boverket, 2022c). The total climate impact of the building is given by summarizing the impact of resource. The resulting total impact of the building is divided by its BTA, and the result is presented as $kgCO_2e/m^2_{BTA}$.

As a part of the climate impact calculations, a coverage rate is calculated (Boverket, 2022b). The coverage rate is a measure of how much of the buildings climate impact that has been calculable. The coverage rate can then be used to compensate for the GHG emissions that were not possible to calculate. By using the coverage rate it is thereby possible to have a result that corresponds to 100% of the buildings' climate impact. The coverage rate is added for A1-A3, A4 and A5.1, and is calculated by dividing the total calculated climate impact by the coverage rate factor. The coverage rate is also a measure of the certainty and quality of the calculations, and how well the calculation represents the actual climate impact of the building. The coverage rate can be calculated using weight, cost or units. It is calculated as the sum of all the resources that it was possible to obtain information regarding weight/cost/units and climate data, divided by the sum of all resource's weight/cost/units. The equation for calculating the coverage rate is presented in equation (2).

Equation (2)
Calculation of coverage rate.

$$\text{Coverage rate [\%] = Weight of studied part(s) [kg] / Weight of the total [kg]}$$

2.5 Category systems

Two different category systems are used to explain and categorize the products in the building.

2.5.1 BSAB83

BSAB83 refers to “Skanska Sveriges Byggdelsregister enligt BSAB83” by Skanska Kalkyl (2014). This translates to “Skanska Sweden’s register of parts of buildings according to BSAB83”. The BSAB83 system categorizes the different parts of a building under categories. A building is divided into 10 parts that are numbered from 0 to 9, see Table 1. These 10 parts are further divided into subcategories. The category and subcategories relevant to this report is building part 8 “Installations”, and the subcategories 84 and 85. The subcategories of building part 8 are seen in Table 2. Subcategories 84 and 85 will be used to compare the calculations in the report to other studies. Building part 84 is equal to the SH system and building part 85 is equal to the CV system. The Tables 1 and 2 from Skanska Kalkyl (2014) are translated into English.

Table 1

BSAB83 categories.

Category	Name	English translation
0	Sanering och rivning	Remediation and demolition
1	Mark	Ground
2	Husunderbyggnad	Foundation
3	Stomme	Structural frame
4	Yttertak	Roof
5	Fasader	Facade-/s
6	Stomkomplettering, rumsbildning	Structural additions, room division
7	Invändiga ytskikt, rumskomplettering	Interior finishes and fittings
8	Installationer	Installations
9	Gemensamma arbeten	Common works

Note. Authors own translations.

Table 2

Subcategories of building part 8 according to BSAB83.

Subcategory	Name	English translation
80	Sammansatta	Composite building components
81	-	-
82	Process	Process
83	Storkök	Commercial kitchen
84	Sanitet, värme	Sanitation, heating
85	Kyla, luft	Cooling, ventilation
86	El	Electrical installations
87	Transport	Transport
88	Styr och regler	Control and automation
89	Speciella installationer	Special installations

Note: Authors own translations.

2.5.2 Product categories

The technical description categorizes the HVAC products into subcategories for both SH and CV. These categorizations are presented in Table 3 for SH and in Table 4 for CV.

Table 3

Categorization of Sanitation and Heating.

Product code	Group name	English translation
PKB	Pumpar	Pumps
PLB	Behållare för fast, flytande eller gasformigt medium	Containers for solid, liquid or gaseous media
PLC	Expansionskärl od	Expansion vessel etc.
PJB	Värmeväxlare	Heat exchanger
PMB	Apparater för rening av fast, flytande eller gasformigt medium	Apparatus for the purification of solid, liquid or gaseous media
PPC	Rörupphängningsdon, expansionselement, rörgenomföringar mm	Pipe suspension devices, expansion elements, pipe penetrations, etc
PRB	Brunnar	Wells
PRC	Spygatter	Spygates
PSA	Ventiler och shuntgrupper med sammansatt funktion	Valves and shunt groups with composite function
PSD	Styrventiler	Control valves
PSE	Självverkande ventiler	Self-acting valves
PSG	Säkerhetsventiler och säkerhetsdon	Safety valves and devices
PTB	Rumsvärmeapparater	Radiators
PUC	Tvättställ, tvättrännor och bidéer	Washbasins, gutters and bidets
PUE	Klosetter, urinaler mm	Closets, urinals, etc.
PUF	Diskbänkar, tvättbänkar, utslagsbackar mm	Kitchen sinks, washbasins, tee trays, etc.
PVB	Tappventiler, blandare mm i tappvattensystem	Drain valves, mixers, etc. in domestic water systems
PVD	Brandposter od	Fire hydrants etc.
PVN	Slangutrustning	Hose equipment
UGA	Mätare med sammansatt funktion	Compound function gauges
UGE	Mätare för flöde	Flow meter
PNU	Rörledningar för installationer	Pipelines, etc.
RC/RD/RE/RBA	Isolering	Insulation

Note: Authors own translations.

Table 4
Categorization of Cooling and Ventilation.

Product code	Group name	English translation
QMB	Uteluftsdon	Outdoor air terminals
QMC	Tilluftsdon	Supply air terminals
QMD	Överluftsdon	Excess air terminals
QME	Frånluftsdon	Exhaust air terminals
QMF	Avluftsdon	Extract air terminals
QMG	Kombinerade utelufts- och avluftsdon	Combined outdoor and exhaust air diffusers
QKC	Ljuddämpare med rektangulär anslutning	Silencer with rectangular connection
QKB	Ljuddämpare med cirkulär anslutning	Silencer with circular connection
QLE	Luckor i ventilationskanal för rensning och inspektion	Hatches in ventilation duct for cleaning and inspection
QLB/QLC	Ventilationskanaler	Ventilation ducts
QJG	Konstanttrycksdon	Constant pressure actuators
QJF	Variabelflödesdon	Variable flow actuators
QJC	Spjäll för skydd mot spridning av brand och brandgas	Dampers for protection against the spread of fire and smoke
QJB	Luftspjäll	Air damper
QFC	Värmeväxlare vätska-luft ed	Heat exchanger liquid-air etc.
QEA	Fläktar av sammansatt konstruktion	Fans of composite construction
QAB	Luftbehandlingsaggregat	Air handling units
RBI	Termisk isolering av ventilationskanal	Thermal insulation of ventilation duct
PTC	Rumskylapparater	Room coolers

Note: Authors own translations.

2.6 Project planning documents and Construction documents

Since both buildings are owned and provided by Akademiska Hus this report will use the same definition of Project planning documents and Construction documents as Akademiska Hus does. In the Project planning documents it´s examined what technical solutions and materials that would be of best use for the building (Akademiska Hus, 2023b). The Project planning documents also provide a picture of the construction and installation of the building. An environmental plan and work environment plan are also included in the Project planning documents. The Project planning documents are thereafter further developed and solidified into Construction documents which act as the execution instructions for the contractors (Akademiska Hus, 2023b). This means that the Construction documents in theory are a much sounder base for climate impact calculations since it has more detail in what is going into the building.

2.7 Reference values used for comparison

As stated in the introduction, new updated reference values were published by Malmqvist et al. (2023) during the progress of this report. The report does not include values for a university building per say but the buildings that are examined can be seen as a combination of both school and office, for which there are reference values. The new reference values include breakdowns that specify building part 84 (Sanitation and Heating) and 85 (Cooling and Ventilation). This makes it easier to compare the results from the report since it is not necessary to use any scaling factors to account for the other parts of the HVAC system. The reference values for building part 84 (Sanitation and Heating) include sprinklers, if these are not calculated for then it should be excluded. The reference values by Malmqvist et al. (2023) can be seen in Table 5.

Table 5

Updated reference values in $kgCO_2e/m^2_{Atemp}$ for A1-A5.1 specifically for building part 84 and 85 (Malmqvist et al., 2023).

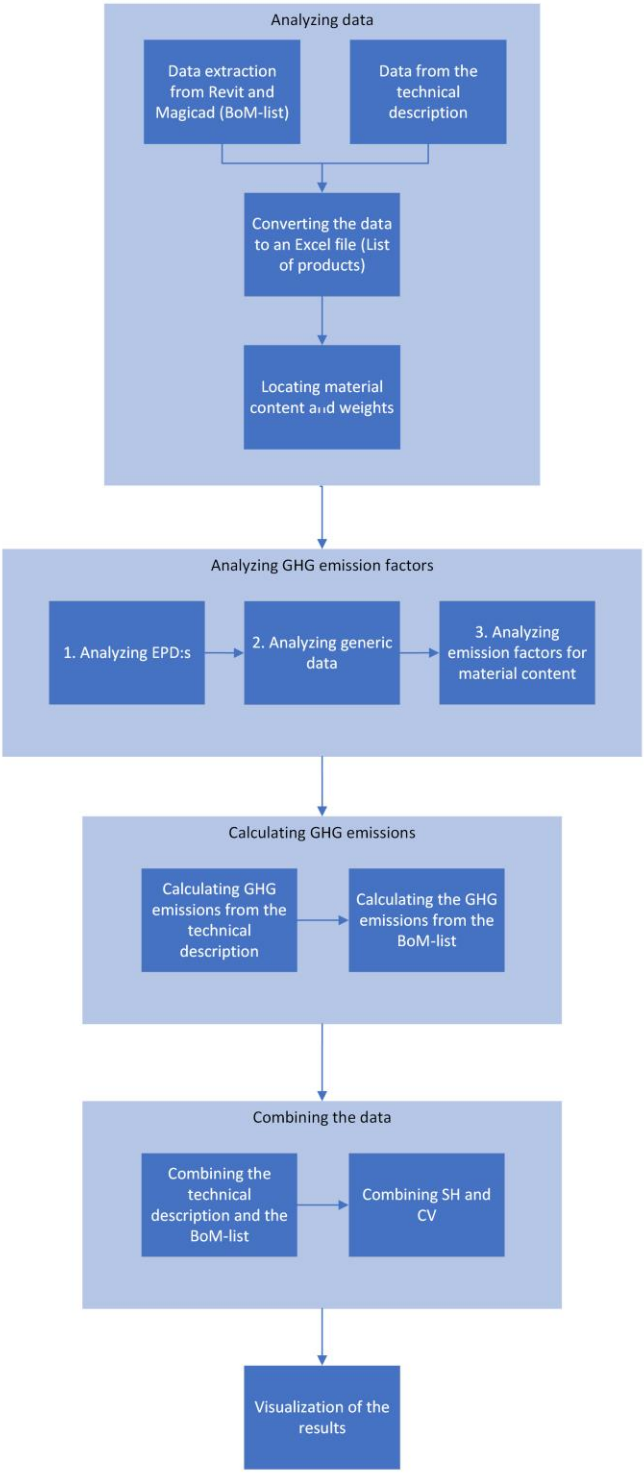
Type of building	Total	SH (84)	SH (Excluding sprinklers)	CV (85)
Office-building	58	22	11	21
School	60	22	11	23

Note. Values in GWP-GHG. The reference values for office and school are mentioned in Table 15 in Malmqvist et al. (2023). The value for sprinklers is found in Table 19 in Malmqvist et al. (2023).

3 Method

At first a literature study was carried out to find information regarding previous studies and to gain knowledge regarding climate impact calculations on buildings in general. Thereafter the method followed the depicted methodology in Figure 4.

Figure 4
Visual description of the method.



3.1 Calculation of the climate impact

The first research question was answered by calculating the climate impact of the two projects provided by Akademiska Hus, that are described in Section 1.4. Umeå Building in Umeå was examined first. This choice was made since Umeå Building was further along in the planning process and had construction documents available, which in turn have a higher level of detail and more data available than Project planning documents. Nya Konst in Gothenburg was examined second, as the project only had Project planning documents available.

The methodology of the climate impact calculations in this report was based on the methodology by Boverket described in Section 2.4, but a key difference is the system boundaries as this report excludes A5.2-A5.5 (Energy). A5.2-A5.5 stands for the energy use on site for constructing the building, to estimate these in early stages reference values can be used (IVL Svenska Miljöinstitutet, 2022b). However, these do not separate the different parts of the building. Since it was unknown what part of these GHG emissions the HVAC system stood for, A5.2-A5.5 was not included.

Overall, the report aimed to have a coverage rate (calculated) of at least 80% of the HVAC systems of the buildings. The climate data that was used for calculation of the climate impact of the two buildings had a preferred priority order. The priority list of data is presented with type of data and database preference, in the list below:

1. EPD
2. Generic data
    2.1. Boverket
    2.2. CO2data.fi
3. Material content
    3.1. Boverket
    3.2. CO2data.fi
    3.3. Ecoinvent

It was most preferable to use EPD’s for the specific products that had them, and when that was not available then generic data for the type of product was used. If there were no EPD’s or generic data available for a product, then the climate data was calculated based on the material content of the products. The databases for generic data were the Swedish database by Boverket and the Finnish database CO2data.fi. The climate data for materials was extracted from Boverket, CO2data.fi, and Ecoinvent v3.8.

When finding emission factors for material content the database Ecoinvent v3.8 was used as a backup when data could not be found elsewhere. Here the value for CML v4.8 2016 with GWP100 was used. CML was used as a baseline methodology for the calculations since it is a requirement for the standards EN 15978 and EN 15804 (OneClick LCA, n.d.).

For the data collected from CO2data.fi and Ecoinvent v3.8 the impact of transportation (A4) and the spillage from the installation process (A5.1) had to be added to the value. A4 was calculated by using an average value that was multiplied with the weight of the product. This value was taken from (Boverket, 2022d). For A5.1 the report looked at spillage, for which multiplying factors were collected from the databases or if they did not exist then a spillage factor was assumed from discussion with Patrik Holmquist, Head of HVAC at WSP Gothenburg and an expert within the field, to estimate the impact for the building (P. Holmquist, personal communication, March 9, 2023).

3.1.1 Gathering of data

Information and data regarding the components of the HVAC systems in the two buildings was provided by Akademiska Hus and extracted through WSP in the form of technical descriptions of the HVAC systems and extracted Bill-of-Material Lists (BoM-lists) from BIM-models. The technical descriptions had information on all components of the Sanitation and Heating (SH) and Cooling and Ventilation (CV) systems. Some products (ducts, pipelines and insulation among others) did not have declared amounts as those are modelled in the BIM-model and therefore the BoM-lists were also extracted to gather the missing information.

The gathering of data began with analyzing the technical descriptions for Umeå Building that was provided by Akademiska Hus through WSP, this was done separately for the SH system and for the CV system. The technical descriptions were then processed for information needed for the climate impact calculation such as number of products, product type, manufacturer and specific product name. A list of products was created from the information in the technical descriptions and the products were categorized under the product-codes for SH and CV.

Using the information in the list of products, each product was searched through the webpages of the companies who provide the products. The aim was to find information on the weight, material content and available EPD´s of the product. If these were not found through the search, then the company in question was contacted by email to gather the missing information if possible. If there were no available EPD’s then Generic data for such a product or the information gathered on material content of the product could be used to calculate the climate impact of the product. Regarding the products from the technical description, some assumptions had to be made to find a weight, material content or climate impact factor. These assumptions are presented in Appendix A.
This data-gathering resulted in an updated list of products with information regarding manufacturer, product name, weight and material content. This was then used as a basis for the climate calculations along with the extracted BoM-lists.

The BoM-lists were provided as an excel file with each specific product in its own row. The specific products were then summarized to make calculations feasible. The ventilation ducts in the CV system and pipelines in the SH system were summarized as lengths in meters and not as specific number of units. The insulation was also a part of the BoM-list but the information regarding insulation was not manageable. This resulted in a separate extraction of data from the HVAC engineer for the insulation where the data was more organized.

3.1.1.1 Exclusions

When analyzing the technical description of the buildings some of the contents there was deemed to be unusable. These products were then taken out of the equations for the climate impact. The products that were excluded and a motivation to why is presented in Appendix B.

3.1.2 Climate impact calculations

The climate calculations were performed in Excel along with the list of products, BoM-lists, EPD´s, Generic data, Material content data. The climate impact for the product was calculated in accordance with equation (1).

The EPD´s used came in different units, most often $kgCO_2e/kg_{product}$ but could also come in $kgCO_2e$/product and then the number of products could be used to calculate the climate impact. Sometimes it was also necessary to convert the unit of the EPD into $kgCO_2e/kg$ if the EPD was specific to a certain dimension of a product or came in another reference unit. For the EPD´s the value for GWP-GHG was used in accordance with Boverket (2022a). As Generic data can also be found in different reference units, such as kg CO2e/kg or kWh or m^2 or product, there were also cases where the unit for generic data had to be converted in the same way as for EPD´s.

Calculating the climate impact based on material content was done by analyzing the material content of a product and multiplying the climate data of the material with the amount of a type of material in the product. The material content data provided by CO2data.fi did not account for A4, which had to be added manually. For this the reference value from Boverket (2022d) was used. For each product a coverage rate of at least 80% of the total material content of the products was aimed for. The emission factor for each material was multiplied with the percentage of the specific material in the product, and then these were summed up and divided with the coverage rate to account for 100% of GHG emissions from the products. Thereafter the results were multiplied with the weight and number of units for the products and 25% was added to the climate impact as an uncertainty factor. The uncertainty factor was chosen based on the methodology by Sustainable Stockholm 2030 (Stigemyr Hill & Borgström, 2022). For a more detailed explanation see equation (3). The GHG emissions for A4 and A5.1 were thereafter added in the same way as described in Section 3.1.

Coverage rate was also used to cover the GHG emissions from all the products of the SH and CV systems. Since it was not possible to find material data on some products, coverage rate was used to cover for this, and the climate impact of these products were thus included in the results.

Equation (3)
Calculating the GHG emissions when using material content.

$$\text{Climate impact } [kgCO_2e] = ((AM1\ [\%]) * (CD1\ [kgCO_2e/kg]) + (AM2\ [\%]) * (CD2\ [kgCO_2e/kg]) + (AM3\ [\%]) * (CD3\ [kgCO_2e/kg])) * (1 / (\text{Coverage rate } [\%])) * (\text{Weight } [kg]) * (\text{Units } [-]) * 1.25$$

Note: AM = Amount of material, CD = Climate data.

When calculating climate impact by using the material content some assumptions regarding the emission factors from the materials included had to be made. This was done since the exact material used was not included in the databases. The assumptions on material and emission factors from them are presented in Appendix C.

Some items in the technical descriptions were a combination of products for which EPD´s existed for a part of the product but not for the combined products. This meant that two separate calculations were performed for these products. First the climate impact from the part with EPD was calculated using the EPD. Thereafter the climate impact for the other parts of the product was calculated using Material content data. The results were then summarized for the combined product.

When calculating Umeå Building the parts that were provided in the BoM-list for the SH system were pipelines, its connections and insulation, and for the CV system it was ventilation ducts, its connections and insulation. The BoM-lists for Nya Konst differed from Umeå Building, see Section 3.2. Since the insulation for Umeå Building was deemed to be unmanageable it was calculated separately with its separate data extraction. To be able to calculate the climate impact of the products in the BoM-lists the weight of the product was necessary, as climate data is provided in $kgCO_2e/kg_{product}$. The data on the BoM-lists often had to be transformed to produce a weight. If there was an EPD the data from the BoM-list was assumed to have the same weight by unit or meter as the EPD. If there was no EPD, a weight could often be located if information regarding model and manufacturer was provided in the BoM-list by using a product data sheet. For the products where there was no information on model or manufacturer a market leading manufacturer was assumed to be the manufacturer for the type of product, so as to be able to retrieve information regarding weight. Or, if no weight could be retrieved by assuming a manufacturer, then a weight was assumed by calculating the volume of the product and multiplied by a density of the material for the product. If a length of a product was provided, then that length could also for some products be multiplied by a factor for weight/meter. If no specific product was found, generic data for a set of products was used. To calculate weight the same assumptions as for a specific product were used here.

3.1.2.1 BoM-list Sanitation and Heating

To calculate the volume for different parts of the SH system some methodology choices and assumptions had to be made. These are presented in Appendix D. If there was no weight provided by the manufacturer a volume had to be calculated for the products and thereafter the results were multiplied with a density. The volume calculations are presented in Appendix E. For the products connected to the BoM-list for the SH system a manufacturer was assumed for all the pipelines and connections. One product code for a pipeline thus had the same manufacturer as a bend, t-branch etc. with the same product code. The manufacturers for the different materials are presented in Appendix F.

3.1.2.2 BoM-list Cooling and Ventilation

The items in the BoM-list that was calculated for the CV system included ventilation ducts, bends, X-branches, T-branches, reducer/expanders and plugs. The products came in three materials: galvanized steel, blacksheet steel and mineral wool. The ventilation ducts had no named manufacturer. Instead, market leading manufacturers were assumed to be the manufacturers, see Appendix F. The weight for each product was found through either product information or assumed by calculating a volume. The volume calculations and the assumptions for the CV system are presented in Appendix E & G. After the volume of a product was calculated then an assumed density could be used to calculate a weight for these products. Data on densities was found in Boverket and CO2data.fi.

3.1.2.3 BoM-list Insulation

The climate impact for the insulation was calculated by first calculating a volume of the products and then multiplying with density and a climate impact factor found in Boverket´s climate database. For the insulation of the CV system the volume could be calculated using data on the amount of surface area and thickness of an insulation type. For CV, this was done for each part of the products provided in the BoM-list for insulation. Weight and climate impact factor was calculated using an EPD and generic data on the density of stone wool, assumed to be “Stone wool, bats and rolls” in Boverket´s database, which was the insulation material according to the technical description.

For SH however, this was only done for the insulation for the pipelines. This was done because the data extracted from the model was insufficient for the rest of the products. Instead, the insulation for the bends, plugs, reducer/expanders, and T-branches were assumed to stand for the same percentage of impact as their counterparts in the BoM-list. This was done so as to not underestimate the climate impact from the insulations. Since the material of the insulation was not specified further than “mineral wool” the assumed insulation used for the pipes was “Stone wool, bats and rolls” from Boverket´s database.

3.1.3 Summarizing the results

Finally, all the results from the technical description, BoM-lists and the insulation were added up both for SH and CV systems respectively but also collectively. Lastly the Climate impact was divided by with the A_{temp} to be comparable with the reference values.

3.2 Differences for calculating Nya Konst compared to Umeå Building

The calculations of Nya Konst followed the same principles as the calculations of Umeå Building. However, due to a difference in the amount of information available the calculations ended up being not as extensive as for Umeå Building.

The project only had Project planning documents available and the information in the technical description was scarce. The BoM-lists were also scarcer for information compared to Umeå Building, resulting in overall less calculable data. The majority of the climate impact calculations were performed with data from the BoM-lists provided, with some additional information from the technical description. The weight and climate data of the products was found or calculated with mostly the same methods as for Umeå Building for the items in the technical description and the BoM-lists. The differences in the calculations are described in Section 3.2.1 and Section 3.2.2.

3.2.1 Differences for Sanitation and Heating

When calculating the climate impact from the SH system there were large gaps in both the technical description and the BoM-list. From the technical description there was always some missing data, most often it was not decided which dimension was going to be used (which was the case with the shunts), or the material data was lacking for the product on the manufacturer's website. From the technical description only one product was provided with satisfying information for calculation. In the BoM-list there were more products with satisfying information. All the pipelines were calculated, and the radiators could be calculated with a generic weight, which was also true for the Domestic water taps and Drainage devices. Since the connecting parts of the pipelines (plugs, rectangular red/exp, rectangular bends and rectangular T-branches) and the insulation was not possible to calculate the GHG emissions were assumed to be of the same order of magnitude compared to the pipelines as for Umeå Building.

3.2.2 Differences for Cooling and Ventilation

For the calculations of the climate impact of the CV system for Nya Konst there were very few products in the technical description that was calculable, as very few items contained information necessary for calculations. These items could be calculated using the same method as for the calculations of the items from the technical description for Umeå Building as the calculable items contained information on model, manufacturer and number of items per product. A weight for the product was found by searching the given model and manufacturer and generic data or material data could be found for the climate impact of the product.

Most of the items in the BoM-list for CV for Nya Konst could be calculated. There were however some items in the BoM-list that could not be calculated due to lacking information regarding the model and manufacturer of the product, and where no feasible assumptions regarding those could be made either. These were therefore excluded. Some items in the BoM-list also completely lacked information and were also excluded. The items that were calculable were ventilation ducts, bends, branches, reducer/expanders, silencers and climate beams. The ventilation ducts, bends, branches and reducer/expanders were calculated with the same method as for Umeå Building as no model or manufacturer were named. All circular ventilation ducts, bends, branches and reducer/expanders were assumed to be galvanized steel ducts as there was no information in the BoM-list on whether it was mineral wool ducts or galvanized steel.

The silencers lacked information regarding model and manufacturer in the BoM-list but that information could be added from the technical description and information on weight and climate data could be located using the same method as for Umeå Building. The climate beams in the BoM-list were assumed to be the same as a climate beam found in the technical description for which climate impact were calculated using material data.

The data on insulation was provided in the BoM-list for Nya Konst and the climate impact of the insulation was calculated using the provided information on surface area with an average thickness, based on the information in the technical description for Nya Konst, and density of “stone wool, bats and rolls” from Boverket to calculate a weight and multiplied with generic climate data.

3.2.3 Difference in calculating the coverage rate for Nya Konst

Since much of the data provided in the Project planning report for Nya Konst was lacking in many regards there were several products that had to be excluded. This led to an issue when calculating the coverage rate. Since not enough products were included to be certain of a coverage rate, a value for the coverage rate was assumed based on a comparison with the coverage rate of Umeå Building.

Two different coverage rates were assumed for Nya Konst, one for SH and one for CV. These were based on assumptions made by comparing the results from Nya Konst with the results from Umeå building, by reading the technical description and gaining knowledge regarding what system choice is used to cool and ventilate the building. Firstly, the product groups climate impact per Atemp was compared between the buildings, if results for Nya Konst was lower than for Umeå Building it acted as an argument that a lower coverage rate was needed to compensate. Thereafter the differences in the two systems to cool and ventilate the building were compared as they affect the climate impact of both the SH and CV systems. Lastly the technical room for heating, cooling and domestic water was analyzed for Umeå Building and how large a share this had for the total climate impact to be able to assume a contribution to the climate impact for Nya Konst as it was excluded due to lack of information.

3.3 Comparison with reference values

To compare the calculated results with the reference values, the calculated results for both Umeå Building and Nya Konst were divided with the A_{temp} of each specific building. Since both Umeå Building and Nya Konst are university buildings they were assumed to be a mix of school and offices, thus the buildings were compared to both of these reference values. By doing this it was possible to compare the broken-down values for building part 84 (Sanitation and Heating) and 85 (Cooling and Ventilation) from the reference value report by Malmqvist et al. (2023). The refence values for SH had to be altered since they included sprinkler systems which none of the studied buildings provided information about. The value for the sprinklers was thereby subtracted from the refence value.

3.4 Hotspot analysis

To find the hotspots from the HVAC system the GHG emissions were sorted into the product codes, to be able to answer the third research question. From here it was possible to identify where the majority of the GHG emissions were located by type of product. From that it was possible to find possible climate impact reducing potentials. Hotspots were located both for Umeå Building in general and for SH and CV separately. Thereafter a product type with large GHG emissions connected to it was analyzed by itself to find possible alternative products on the market with a lower climate impact. When finding such a product it was analyzed how big the emission reduction would be if implemented completely into the building.

The hotspot analysis also included a division of the GHG emissions into the different life cycle stages. This was done by altering the emission factors to only include A1-A3, A4, or A5.1. By doing this it was possible to easily see where the GHG emissions occur and where the potential for improvement lies.

3.5 Comparing Project planning documents with Construction documents

The fourth research question was answered by analyzing whether it was possible to accurately calculate the climate impact from HVAC systems when only the Project planning documents are available, or if it is necessary to wait until the Construction documents has been made available. These documents have different levels of detail in the data and thus vary in how much that can be calculated. The two types of documents have been described in Section 1.4. To compare the results from the different documents, the GHG emissions from the different product groups were compared between both buildings. I.e., when the GHG emissions from Nya Konst (Project planning documents) were calculated the results were compared with the GHG emissions from the same product groups in Umeå Building (Construction documents). By doing this an estimation could be made of how much of the total GHG emissions from the HVAC system was calculated from the Project planning documents.

3.6 Sensitivity analysis

A sensitivity analysis was first carried out by changing the values for Umeå Building that were gathered in Ecoinvent from the impact assessment method CML v4.8 2016 to EDIP and thereafter to CML 2001. Thereafter a second sensitivity analysis for Umeå Building was conducted on the assumption of a 25% uncertainty factor used for material content data. This was done by comparing the original results, when using a 25% add on for uncertainty for Material content data, with the result if this add on had not been used.

4 Results and analysis

The climate impact from the HVAC systems of Umeå Building and Nya Konst have been calculated according to the method and the results are presented within the sections below.

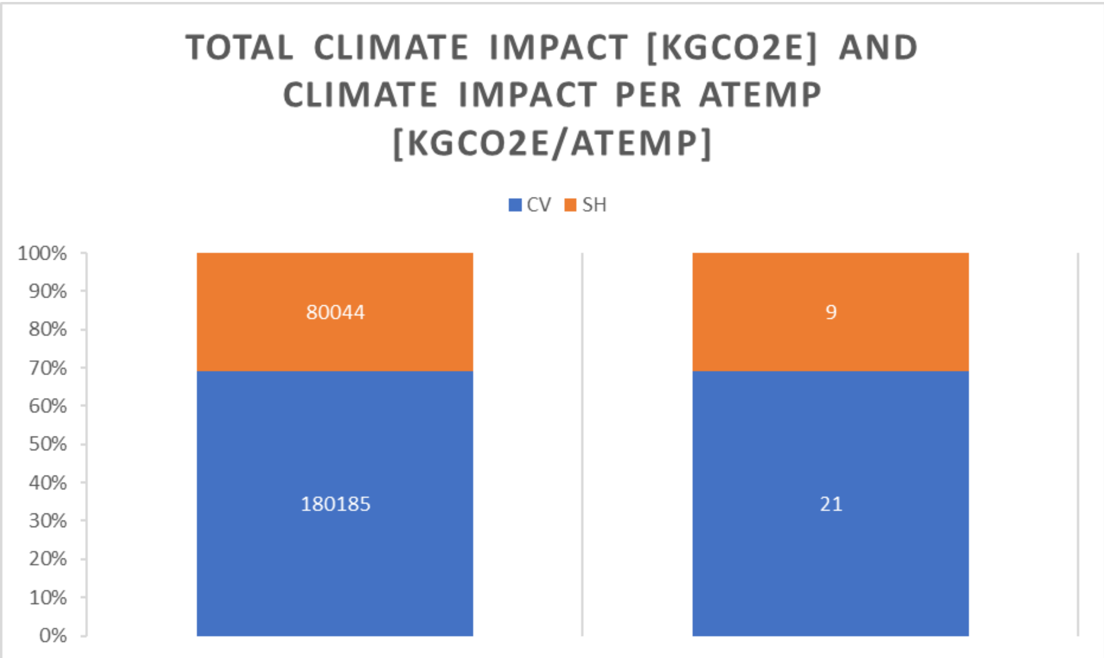
4.1 Results from Umeå Building

Umeå Building was calculated with construction documents and thus has a higher degree of certainty. The results, however, are still in many cases based on assumptions, but the input data was deemed to be enough to calculate the climate impact for Sanitation and Heating (SH) and Cooling and Ventilation (CV). The results for Umeå Building include A1-A5.1. The results for Umeå Building include the coverage rate by weight which was calculated to be 93%.

4.1.1 Total climate impact for Umeå Building

The climate impact from Umeå Building is presented in Figure 5. The data is divided into both SH and CV. The total climate impact for Umeå Building is 260,229 $kgCO_2e$ and when divided with A_{temp} it is 30 $kgCO_2e/m^2{}_{Atemp}$.

Figure 5
Total Climate impact and Climate impact / A_{temp} for CV and SH for Umeå Building.



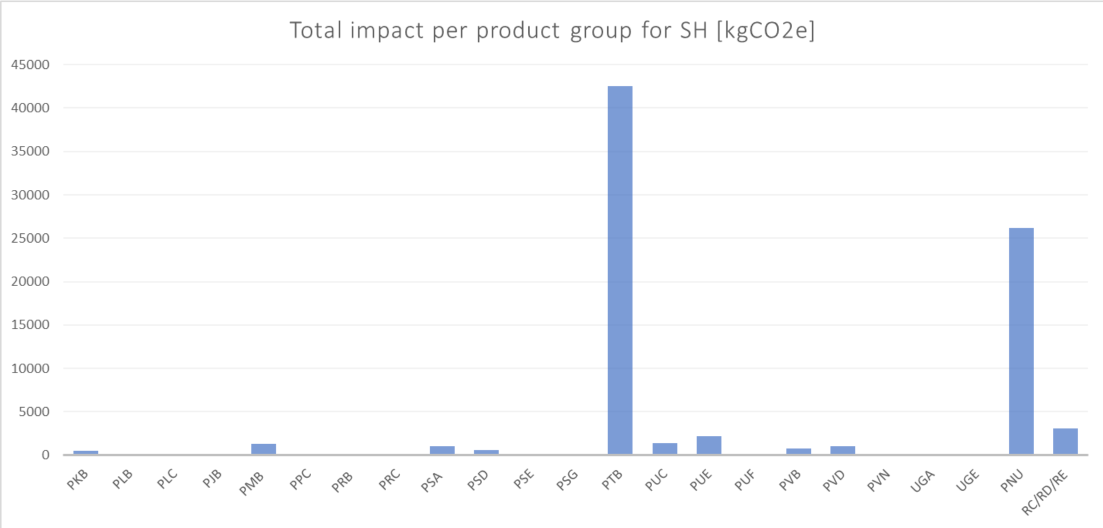
4.1.2 Climate impact from the product groups for Umeå Building

The results are divided into SH and CV. In Figure 6 and 8 the results are presented as amount of GHG emissions per product group, and in Figure 7 and 9 the share of the total climate impact per product groups for SH and CV are presented. As seen in the figures, some of the product groups appear to not have any GHG emissions connected to them. This is a consequence of some product groups having very large GHG emissions compared to others. However, there are some product groups that do not have any GHG emissions connected to them at all due to lack of data on material content.

These are PVN, PPC and PJB in Figure 6 and 7. This is not the case in reality, but since it was not possible to calculate them, their GHG emissions are included in the coverage rate in the final results.

Figure 6

Climate impact for each product group for SH in Umeå Building.



Note: PKB = Pumps , PLB = Containers for solid, liquid or gaseous media , PLC = Expansion vessel etc. , PJB = Heat exchanger , PMB = Apparatus for the purification of solid, liquid or gaseous media , PPC = Pipe suspension devices, expansion elements, pipe penetrations, etc , PRB = Wells , PRC = Spygates , PSA = Valves and shunt groups with composite function , PSD = Control valves , PSE = Self-acting valves , PSG = Safety valves and devices , PTB = Radiators , PUC = Washbasins, gutters and bidets , PUE = Closets, urinals, etc. , PUF = Kitchen sinks, washbasins, tee trays, etc. , PVB = Drain valves, mixers, etc. in domestic water systems , PVD = Fire hydrants etc. , PVN = Hose equipment , UGA = Compound function gauges , UGE = Flow meter , PNU = Pipelines, etc. , RC/RD/RE = Insulation

Figure 7

Share of the climate impact for each product group for SH in Umeå Building.

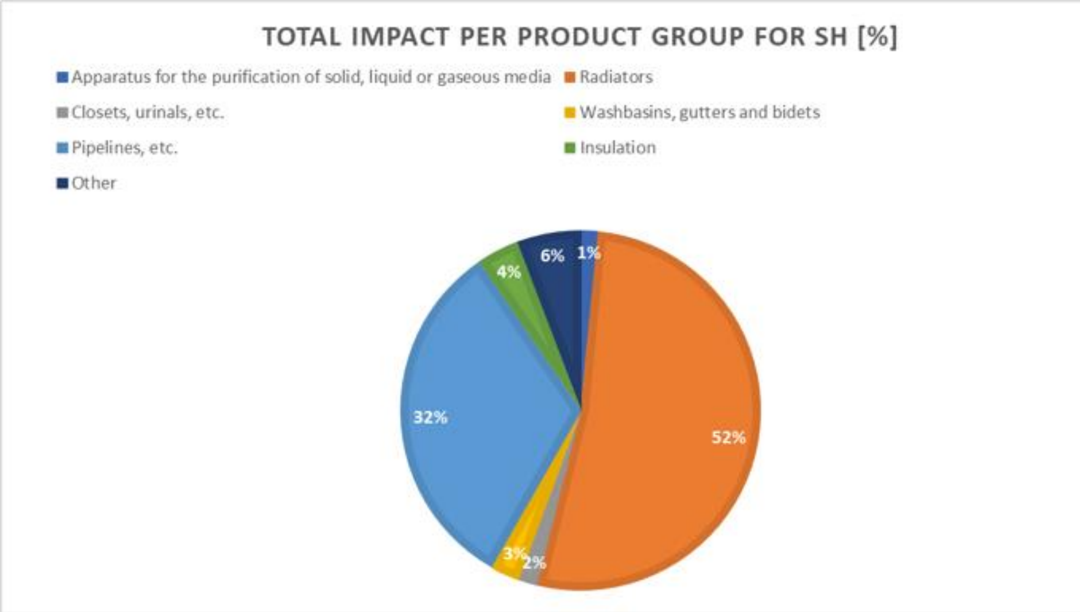
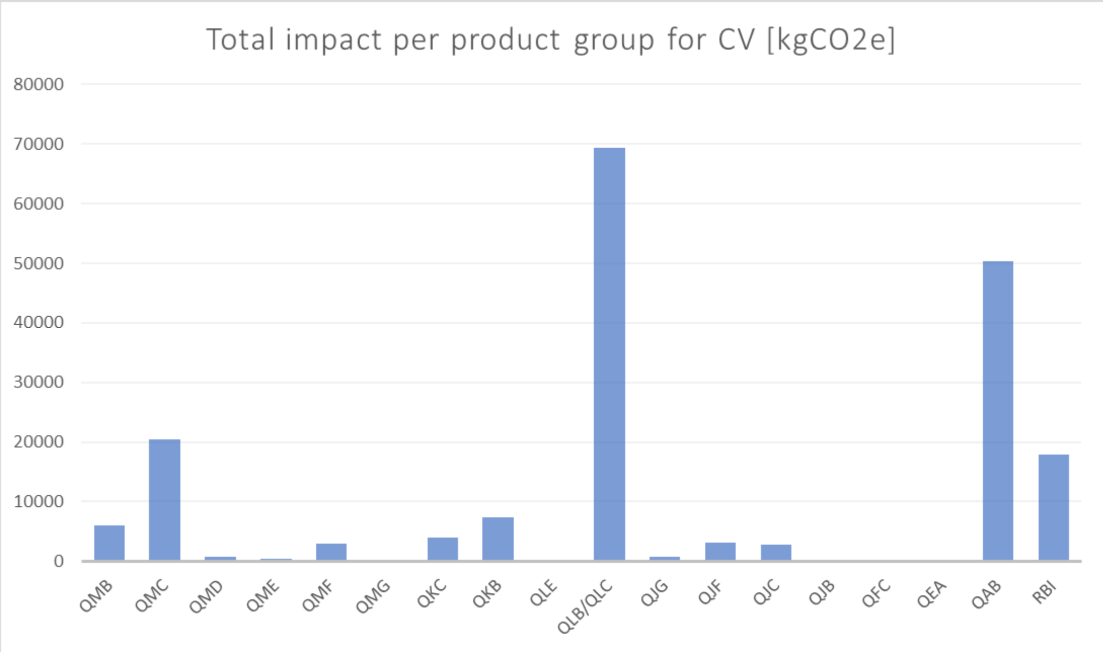


Figure 8

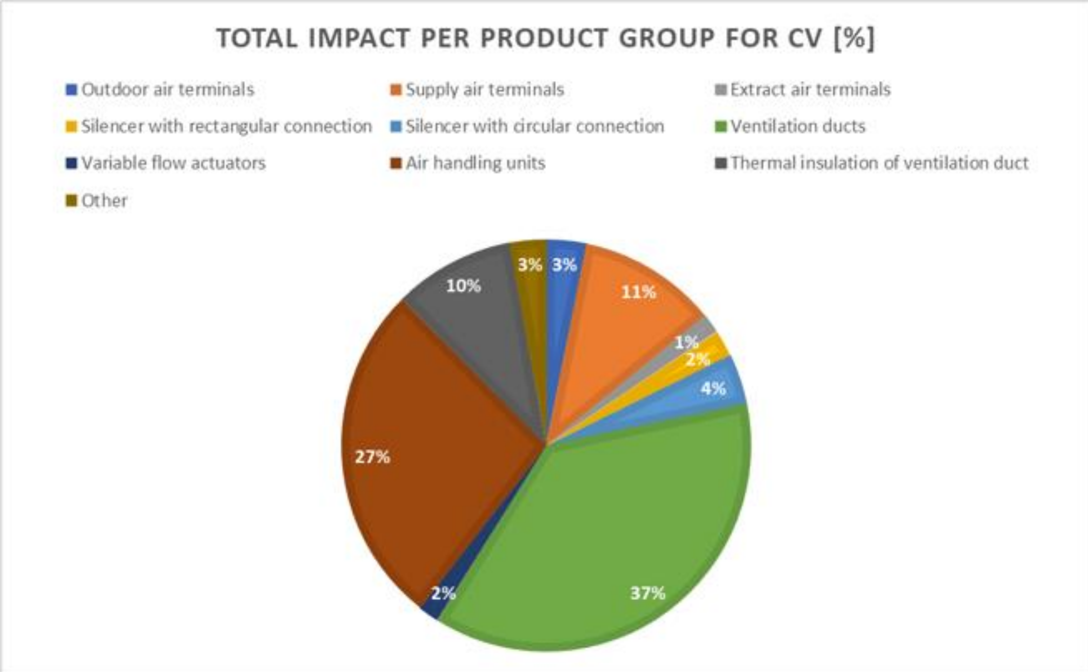
Climate impact for each product group for CV in Umeå Building.



Note: QMB = Outdoor air terminals , QMC = Supply air terminals , QMD = Excess air terminals , QME = Exhaust air terminals , QMF = Extract air terminals , QMG = Combined outdoor and exhaust air diffusers , QKC = Silencer with rectangular connection , QKB = Silencer with circular connection , QLE = Hatches in ventilation duct for cleaning and inspection , QLB/QLC = Ventilation ducts , QJG = Constant pressure actuators , QJF = Variable flow actuators , QJC = Dampers for protection against the spread of fire and smoke , QJB = Air damper , QFC = Heat exchanger liquid-air etc. , QEA = Fans of composite construction , QAB = Air handling units , RBI = Thermal insulation of ventilation duct

Figure 9

Share of the total climate impact for each product group for CV in Umeå Building.

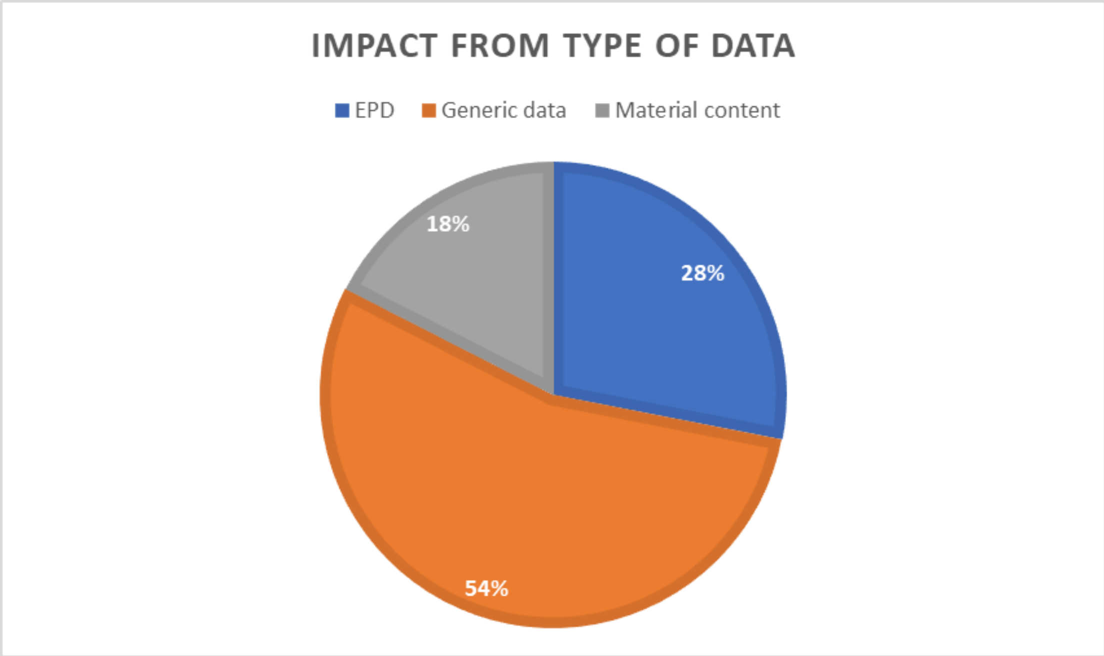


4.1.3 Type of data Umeå Building

The different types of data used to calculate the GHG emissions and how much GHG emissions are derived from them are shown in Figure 10. Here it is clear that Generic data is the most common, EPD is clearly the second most used and Material content is the least used. This is mostly due to the large GHG emissions from the generic products, since it is the most common for both the ventilation ducts and pipelines and that the radiators and air handling units are derived from Generic data. These are products with large GHG emissions and thus it has a large impact on the entire systems.

Figure 10

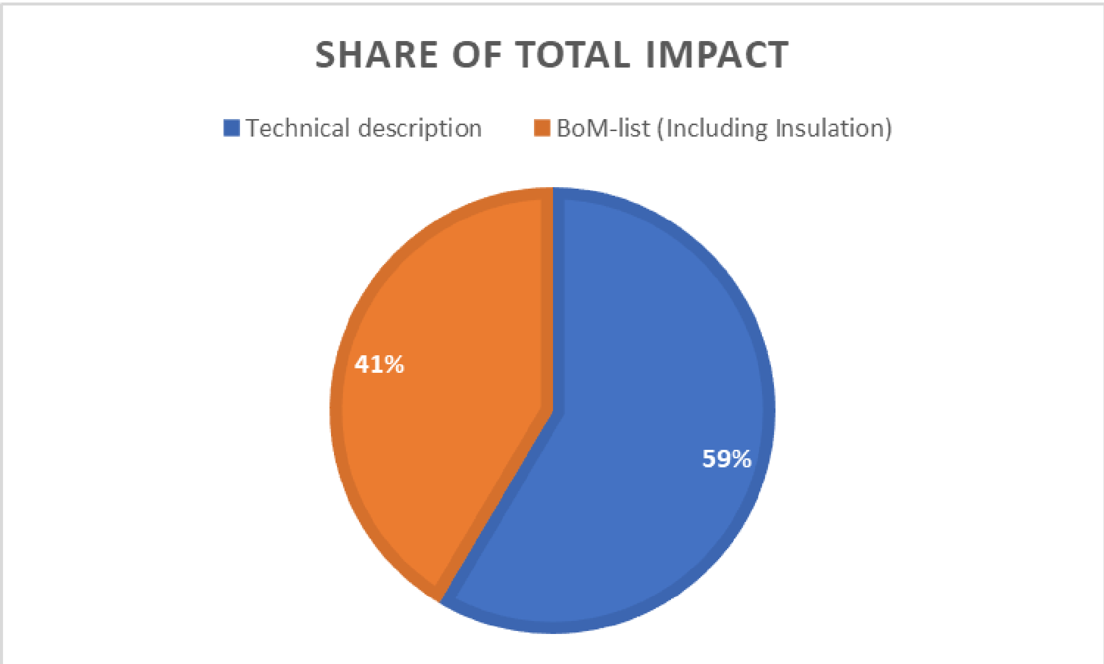
Share of the total impact based on different types of data for Umeå Building.



The different types of data are also divided into technical description and BoM-list. The share of the GHG emissions that are calculated from the technical description and the BoM-list respectively are presented in Figure 11.

Figure 11

Share of the total impact for the data originating from the technical description and BoM-list respectively for Umeå Building.



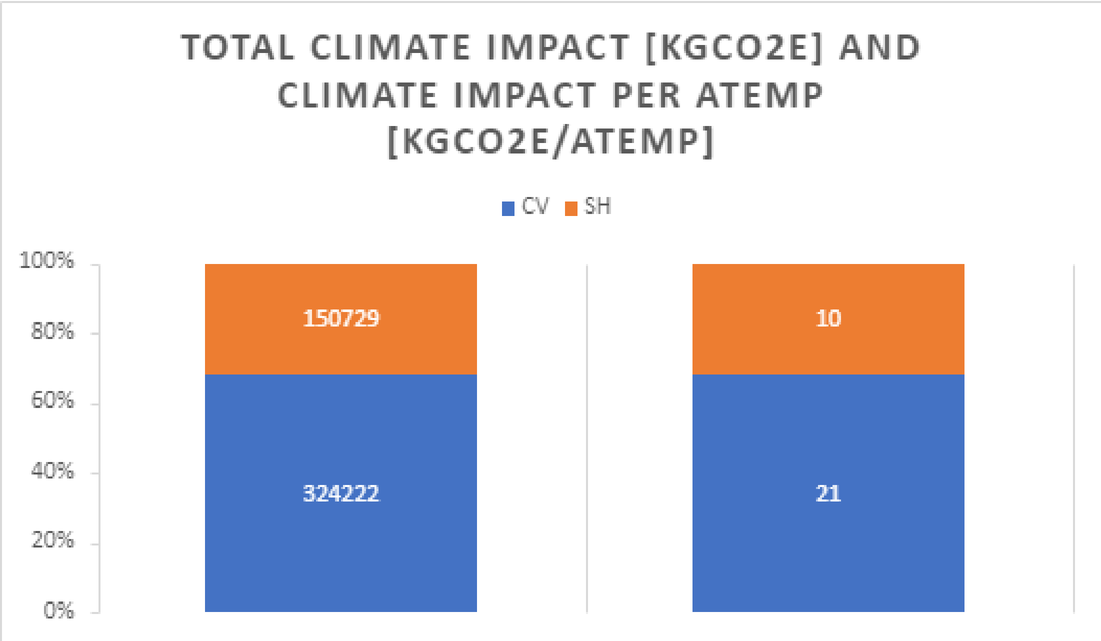
4.2 Results from Nya Konst

Nya Konst was calculated with Project planning documents and thus has a lower degree of available data and certainty. The results are therefore in some cases based on assumptions that are drawn from the results from Umeå Building.

4.2.1 Total climate impact Nya Konst

The climate impact from Nya Konst is presented in Figure 12. The data is divided into both SH as well as CV. The total climate impact for Nya Konst is 474,951 $kgCO_2e$ and when divided with Atemp it is 31 $kgCO_2e/m^2_{Atemp}$. These results include a coverage rate of 65% for SH and 95% for CV.

Figure 12
Total Climate impact and Climate impact / A_{temp} *for CV and SH for Nya Konst.*

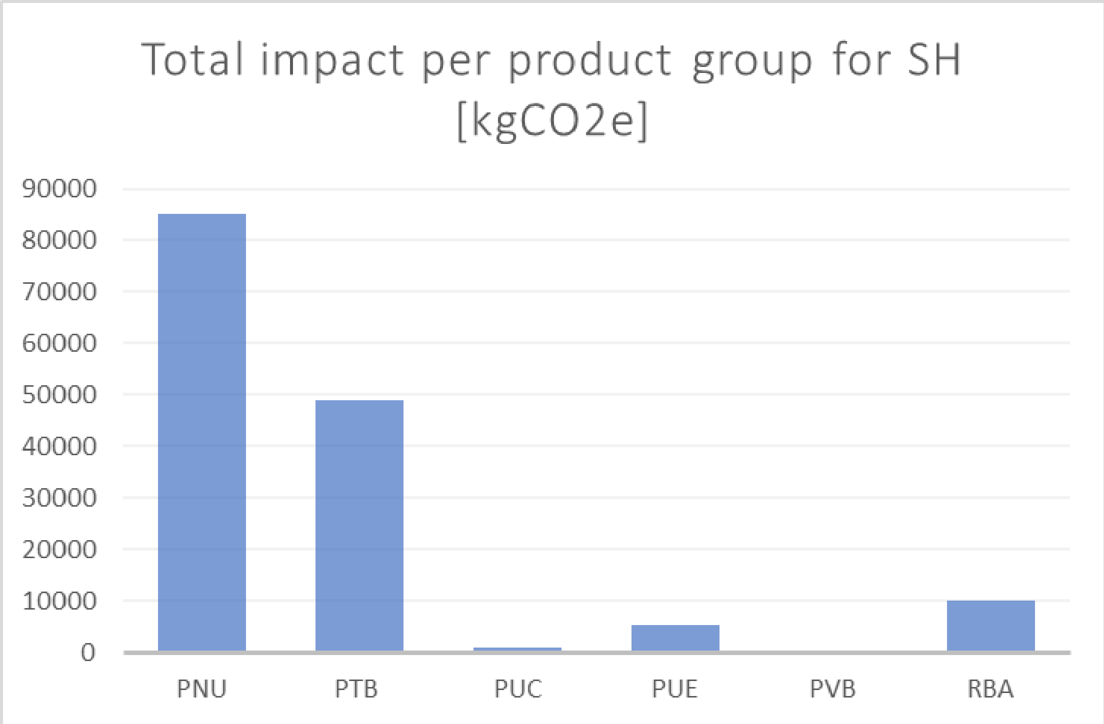


4.2.2 Climate impact from the product groups Nya Konst

The results are divided into SH and CV. In Figure 13 and 15 the results are presented as amount of GHG emissions per product group, and in Figure 14 and 16 the share of the total climate impact per product groups for SH and CV are presented. Since not many categories could even be calculated, only the product groups that were calculated are presented in the results. However, PVB has much lower GHG emissions connected to it compared to others and therefore appears to have no GHG emissions to it. The assumed coverage rates are included in the results.

Figure 13

Climate impact for each product group for SH in Nya Konst.



Note: PNU = Pipelines, etc. , PTB = Radiators , PUC = Washbasins, gutters and bidets , PUE = Closets, urinals, etc. , PVB = Drain valves, mixers, etc. in domestic water systems , RBA = Insulation.

Figure 14

Share of the total climate impact for each product group for SH in Nya Konst.

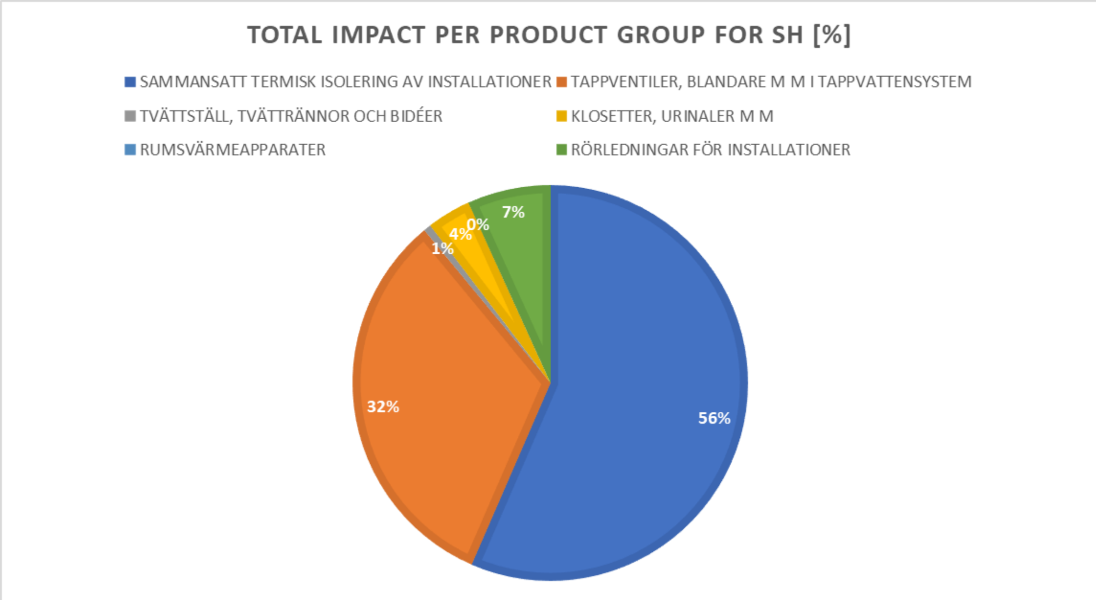
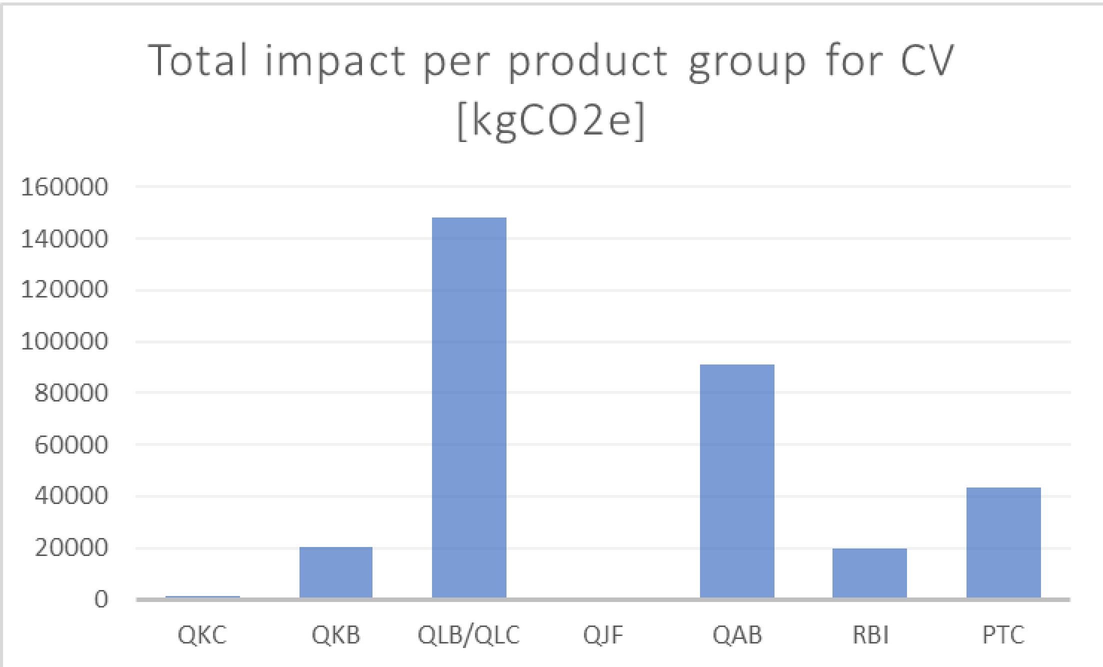


Figure 15

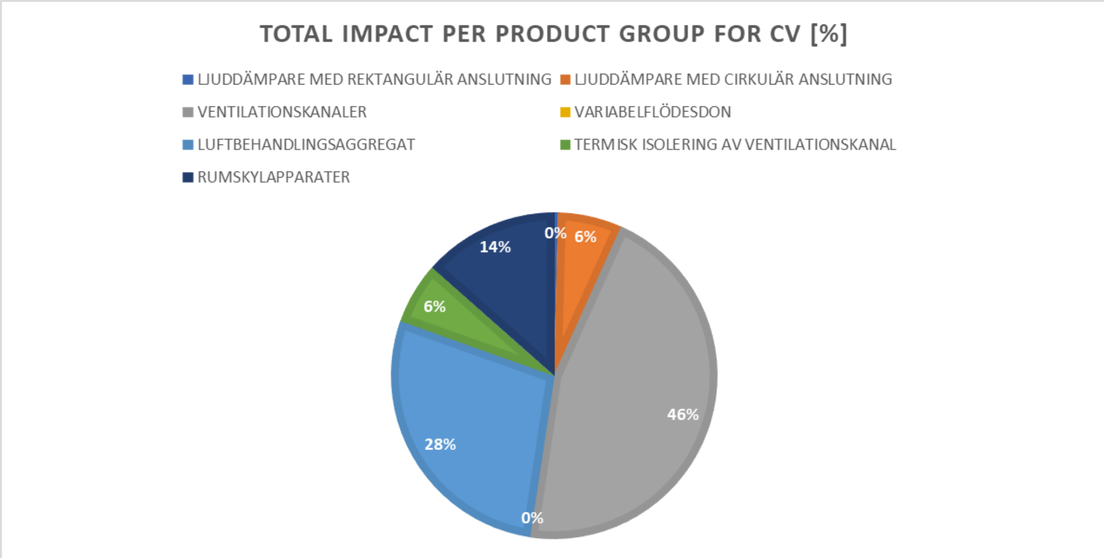
Climate impact for each product group for CV in Nya Konst.



Note: GKC = Silencer with rectangular connection , QKB = Silencer with circular connection , QLB/QLC = Ventilation ducts , QJF = Variable flow actuators , QAB = Air handling units , RBI = Thermal insulation of ventilation duct , PTC = Room coolers.

Figure 16

Share of the climate impact for each product group for CV in Nya Konst.



4.3 Comparison of the calculations with the reference values

The results from the calculations of the climate impact compared to the reference values can be seen in Table 6. The calculated results are close to the reference values but are all lower than the reference values.

Table 6

The calculated climate impact for Umeå Building and Nya Konst in $kgCO_2e/m^2_{Atemp}$ compared to the reference values by Malmqvist et al. (2023)

Building part	Umeå Building	Nya Konst	Office	School
SH	9	10	11	11
CV	21	21	21	23
Total	30	31	32	34

Note: Numbers in GWP-GHG. For the reference value for office and school for 84 the impact from sprinklers has been removed from the value mentioned in Table 15 in Malmqvist et al. (2023). *The value for sprinklers is found in Table 19 in* Malmqvist et al. (2023).

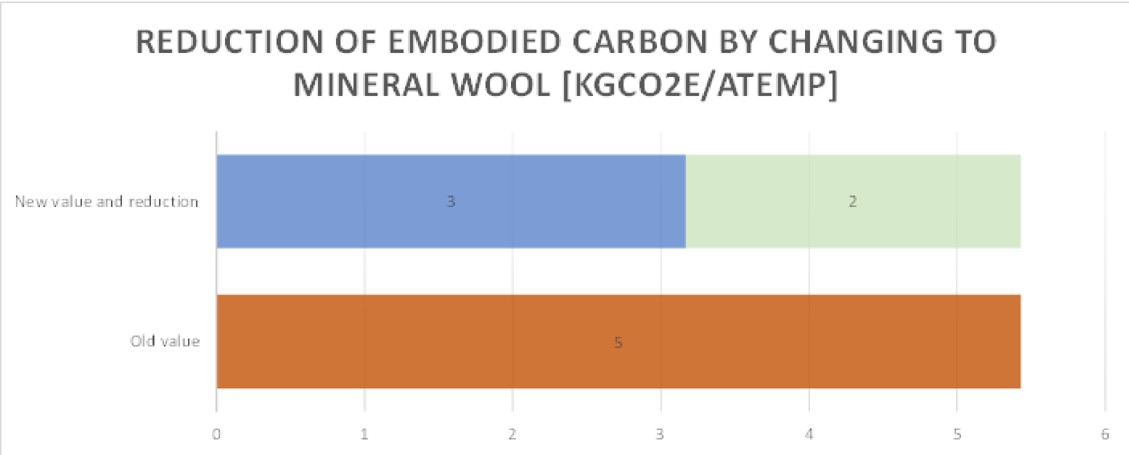
4.4 Hotspot analysis

A hotspot analysis resulted in several hotspots, most notably Air handling units (QAB) and Ventilation ducts (QLB). Both of these are part of the CV system which corresponds to the climate impact from the CV system, which is more than twice as high as for the SH system. If the SH system is analyzed by itself, the two hotspots would be Radiators (PTB) and Pipelines (PNU).

4.4.1 Analysis of emission reduction potential

Based on the hotspot analysis a potential path for reducing GHG emissions has been identified. One way to decrease the climate impact is by changing all the circular ventilation ducts to mineral wool ducts from Climate recovery. This would lead to a decrease of 19,480 $kgCO_2e$ which stands for 7.5% of the total GHG emissions of the building. The reduction of climate impact is presented in Figure 17. This is however a very theoretical potential as the mineral wool ducts do not come in the largest sizes of ventilation ducts.

Figure 17
Impact of changing the circular ventilation ducts to mineral wool ducts for Umeå Building.

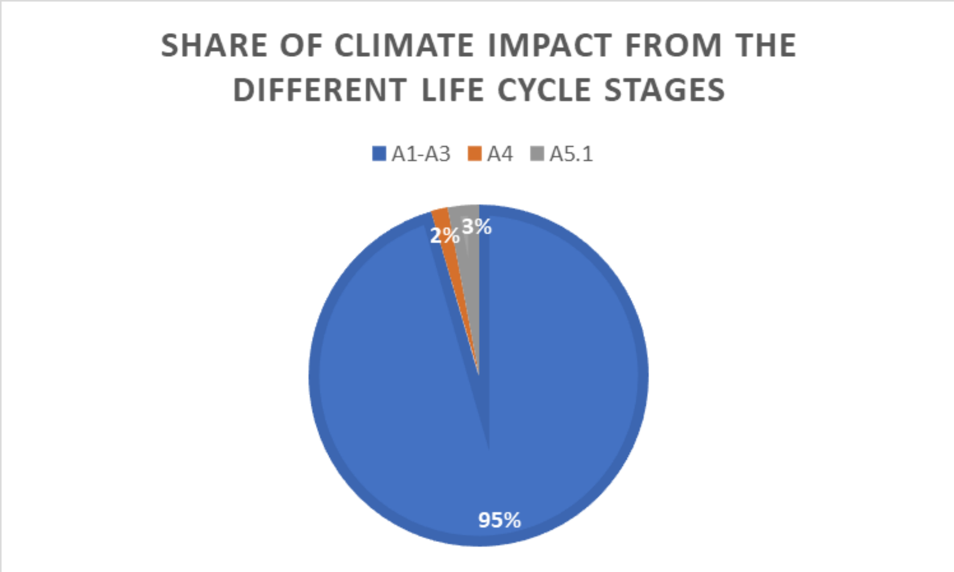


4.4.2 Analysis of the life cycle stages of the building

The hotspot analysis also included an analysis of the GHG emissions from the life cycle stages A1-A3, A4 and A5.1 for Umeå Building. The result from this analysis is presented in Figure 18. The results clearly show that the majority of the GHG emissions come from the construction phase of the products (A1-A3), and thus is where the largest potential for improvement also lies.

Figure 18

Share of climate impact from the different life cycle stages for Umeå Building.



4.5 Comparison of Project planning documents and Construction documents

The calculations carried out with Project planning documents were to a much higher degree based on assumptions. The results are therefore less certain. Table 7 and 8 show what categories could be calculated for Nya Konst and then the same categories for Umeå Building, what the product categories climate impact per Atemp is and what percentage of GHG emissions that accounts for. This shows that in this case it is still possible to account for the majority of GHG emissions based on the information in Project planning documents if a reference building exists. By dividing the climate impact by Atemp for each product group it becomes clear that the value per Atemp can be different for the buildings independent of what the percentage is. The values for radiators in particular vary a lot in climate impact per Atemp. It is therefore important to not only look at the share of GHG emissions but to also analyze each product group itself. This means that it is hard to draw conclusions from the results when calculating with Project planning documents.

Table 7

Comparison of the results from Project planning documents and Construction documents SH.

Product code	Product group	Climate impact per Atemp Nya Konst [kgCO$_2$e/ Atemp]	Share of GHG emissions Nya Konst [%]	Climate impact per Atemp Umeå Building [kgCO$_2$e/ Atemp]	Share of GHG emissions Umeå Building [%]
PNU	Pipelines, etc.	3.59	56.53%	3.04	32.21%
PTB	Radiators	2.06	32.48%	4.94	52.34%
PUC	Washbasins, gutters and bidets	0.04	0.62%	0.16	1.69%
PUE	Closets, urinals, etc.	0.23	3.61%	0.25	2.65%
PVB	Drain valves, mixers, etc. in domestic water systems	0.001	0.01%	0.09	0.94%
RBA	Insulation	0.43	6.75%	0.36	3.85%
Sum			100%		93.69%

Table 8

Comparison of the results from Project planning documents and Construction documents CV.

Product code	Product group	Climate impact per Atemp Nya Konst [$kgCO_2e$/ Atemp]	Share of GHG emissions Nya Konst [%]	Climate impact per Atemp Umeå Building [$kgCO_2e$/ Atemp]	Share of GHG emissions Umeå Building [%]
QKC	Silencer with rectangular connection	0.08	0.41%	0.45	2.10%
QKB	Silencer with circular connection	1.27	6.34%	0.85	3.94%
QLB/QLC	Ventilation ducts	9.11	45.60%	8.05	37.16%
QJF	Variable flow actuators	0.01	0.04%	0.36	1.64%
QAB	Air handling units	5.60	28.05%	5.85	27.01%
RBI	Thermal insulation of ventilation duct	1.22	6.10%	2.07	9.56%
PTC	Room coolers	2.69	13.46%		Not included
Sum			100%		81.42%

4.6 Sensitivity analysis for Umeå Building

The results from the first sensitivity analysis, where different impact assessment methods are examined, are presented in Table 9 where they are compared to the original results. It is clear that the results don't vary in any major direction and the choice of impact assessment method is not the most important when conducting climate calculations on the HVAC system of a building. If these values had been presented in $kgCO_2e/m^2_{Atemp}$ instead there would have been no visible difference in the results.

Table 9

Sensitivity analysis, Impact assessment method choice.

	CLM 4.8 [$kgCO_2e$]	EDIP [$kgCO_2e$]	CML 2001 [$kgCO_2e$]
CV	180,185	180,179	180,181
SH	80,044	80,096	80,080
TOTAL	260,229	260,276	260,261
Difference		+47	+32

When analyzing the impact of the 25% add on for the Material content emissions the results vary more but still not in any major way. The result of the second sensitivity analysis on the 25% add on is presented in Table 10.

Table 10
Sensitivity analysis, 25% add on. Values in table are in kgCO_2e.

	With 25% add on	Without 25% add on	With 25% add on / Atemp	Without 25% add on / Atemp
CV	180,185	175,096	21	20
SH	80,044	75,918	9	9
TOTAL	260,229	251,014	30	29
Difference		-9,215		-1

The results of the sensitivity analysis show that varying the assumptions regarding the data for Material content, which is the most uncertain data, does not have large effects on the final results.

5 Discussion

Throughout the progress of this report, a number of methodological choices have been made. This chapter will discuss these choices and the results of the report.

5.1 Discussion of the results

The results from the comparison of the calculated values for Umeå Building and Nya Konst to the reference values by Malmqvist et al. (2023), seen in Section 4.3, show that the calculated values for both buildings are close but slightly lower than the reference values. The results are deemed to be reasonable as they are similar to the reference values to both types of buildings as the studied buildings can be seen as a combination of school and offices.

The results of the buildings are also very similar to each other. The results of Umeå Building are deemed to be an accurate representation of the building as it is based on Construction documents. The accuracy of how the results represent Nya Konst when the building is completed is less certain, as it is based on Project planning documents. As the two buildings have different system choices it should in theory lead to differences between values for Sanitation and Heating (SH) and Cooling and Ventilation (CV) between the buildings.

The calculated value for the SH system for both Umeå Building and Nya Konst are also very close to each other. This is mostly due to the high impact of the coverage rate, since the coverage rate was largely based on a comparison of the buildings it is therefore reasonable that the end results reflect this. In theory the climate impact from the CV system should have been lower for Nya Konst than for Umeå Building. Since the use of climate beams results in smaller ventilation ducts and smaller air handling units. This reduction could however be replaced by the increase of GHG emissions from the assumption of all ventilation ducts being made from galvanized steel and by the impact of the climate beams themself. However, since many assumptions for Nya Konst was based on Umeå Building it is for this study reasonable that they are close to each other. There have also not been other studies that include climate beams as a building's main source of cooling to compare the results of this study to. The reference values are also based on buildings with the type of cooling and ventilation system that Umeå Building has, which uses air conditioning (Malmqvist et al., 2023).

5.2 Coverage rate for Nya Konst

When deciding on the coverage rate for SH and CV for Nya Konst the differences between the two system choices for cooling and ventilation were discussed. Since Nya Konst uses climate beams instead of "cooling with air conditioning" it should influence the climate impact from the SH and CV system. When looking at the coverage factor for the CV system, it uses cooling by air conditioning which needs a larger flow of air, and the ventilation ducts should thereby have a larger climate impact. Also, the product groups for the CV system with the largest climate impact, ventilation ducts and air handling units, could be calculated for Nya Konst. Supply air terminals could not be calculated for Nya Konst. However, for Nya Konst the climate impact of the climate beams is added as a new product group that is not present in Umeå Building. The coverage rate for the CV system was therefore deemed to be high, at 95%.

Cooling with climate beams uses large water pipes to direct the water into the climate beams, which should increase the climate impact from the SH system. Several product groups for the SH system belong to the technical room for heating, cooling and domestic water. Since it was not possible to calculate a climate impact for the technical room for heating, cooling and domestic water in Nya Konst the percentile for Umeå Building was added to the coverage rate for Nya Konst. Also, when comparing the climate impact per Atemp for the different product groups, the value for radiators was much lower for Nya Konst than for Umeå Building. As the radiators have a large climate impact, it indicated that the coverage rate was lower. The coverage factor for the SH system for Nya Konst was therefore deemed to be lower, at 65%.

5.3 Comparison to other studies

The results of Umeå Building (30 $kgCO_2e/m^2_{Atemp}$) and Nya Konst (31 $kgCO_2e/m^2_{Atemp}$) can also be compared to the other studies mentioned in Section 1.5. Some of these reports presented their results in $kgCO_2e/m^2_{BTA}$, this meant that the results from Umeå Building and Nya Konst had to be transformed. This was done by using a conversion factor of 1/0.9 from A_{temp} to BTA (Energimyndigheten, 2010). The values for Umeå Building and Nya Konst were then 33.6 and 34.2 $kgCO_2e/m^2_{BTA}$ respectively.

A report with similar methodology to this report is the report by Enebjörk et al. (2022). As mentioned in Section 1.5 this report studied two office buildings and they have different choices for the system, for example Building 1 is heated with traditional radiators and Building 2 is heated primarily with the ventilation system, and only has a few radiators. The impact from the SH system and the CV system for Building 1 was in total 23 $kgCO_2e/m^2_{BTA}$ (9 and 14 $kgCO_2e/m^2_{BTA}$ respectively) and for Building 2 it was 31 $kgCO_2e/m^2_{BTA}$ (3 and 28 $kgCO_2e/m^2_{BTA}$ respectively). The study was based on information from BIM-models and technical descriptions. Compared to these it can be concluded that heating with radiators has a large effect on the climate impact from the SH system. Since both Umeå Building and Building 1 uses radiators for heating and the results are close it strengthens the results for the SH system of the report. For the CV system it varies, which could be explained by the goal of Building 1 to reduce their GHG emissions by half, but it is however not a certain foundation for conclusions.

The report written on the construction of the preschool “Hoppet” in Gothenburg shows that the calculated total climate impact (A1-A3) of the preschool is 35 $kgCO_2e/m^2_{BTA}$ (Calderon et al., 2022). This result includes an electrical system which is not calculated for Umeå Building and Nya Konst. Without the electrical system it’s 20 $kgCO_2e/m^2_{BTA}$. Which is lower than both Umeå Building and Nya Konst. The Hoppet-project however, had a mission to lower the embodied carbon so it is reasonable for it to be lower.

The other studies mentioned in the report, Lappalainen (2021), Kiamili et al. (2020) and Ylmén et al., (2019) are difficult to compare with as those have different system boundaries to this report.

5.4 Potential to simplify the calculations

By only calculating the six largest contributors of climate impact of the product groups the coverage would end up at 81%. These groups are presented in Table 11 together with their allocated GHG emissions.

For PNU and QLB/QLC the connecting components for the pipelines and ventilation ducts are included. If they are excluded instead and only the pipelines and ventilation ducts are calculated the GHG emissions from these groups end up at 73% of the total GHG emissions. This is what would be recommended since the extraction of data for the connecting parts is very time consuming, and the climate impact calculations are often based on assumptions. To compensate for the for the GHG emissions from the excluded product groups an add on would have to be introduced. More studies are however needed to decide the value of the add on for this type of building with certainty.

Table 11

Product groups with the most GHG emissions. Values in table are in kgCO_2e.

Product code	Product group name	Climate Impact (Including connecting parts)	Climate Impact (Excluding connecting parts)
PTB	Radiators	39,446	39,446
PNU	Pipelines, etc	24,276	22,296
QLB/QLC	Ventilation ducts	64,257	46,783
QAB	Air handling units	46,712	46,712
QMC	Supply air terminals	18,993	18,993
RBI	Thermal insulation of ventilation duct	16,538	16,538
Sum		210,223	190,769
Percentage of total		**81%**	**73%**

5.5 Comparison of Project planning documents and Construction documents

The most prominent difference in the types of documents is the level of detail that the products have that are going into the HVAC systems of the buildings. For the Project planning documents it was common that the type of product was included but not the exact model of it, making the climate impact calculations harder if not impossible for some products. For the Construction documents however, the specific model was often included and the calculations were possible.

The calculations for Nya Konst (Project planning documents) were to a higher degree based on assumptions than Umeå Building (Construction documents) due to the fact that in some cases, the assumptions for Nya Konst were drawn from the results from Umeå Building. Without the results from Umeå Building, Nya Konst would not have been calculable to the extent that was possible now. This does however show that if there is a reference project to make assumptions from, and generic data can be used, it is possible to roughly calculate large parts of the GHG emissions from a building in the early stages. This is mostly due to the Project planning documents for Nya Konst including the parts of the building with the highest emission connected to it. Based on the results of the report the six product groups identified in the hotspot analysis should preferably be designed with a high detail level already in the Project planning documents, to be able to calculate the climate impact in an earlier stage. For Nya Konst however, since the percentage of the GHG emissions within the product groups vary amongst themselves it is not a certain foundation for conclusions even though the total amount is high. In general, the results from Nya Konst are therefore not as certain and it is not recommended to draw conclusions from these.

In terms of differences between what information was available, Nya Konst only contained information about a few product groups. However, of the six groups identified to be able to be calculated in a simplified calculation, see Table 11, only supply air terminals completely lacked information. Supply air terminals were missing in both the BoM list and technical description for Nya Konst. As supply air terminals were a big impact category for Umeå Building, this could have affected the results as the impact from the supply air terminals could not be included in the final result.

5.6 Sources of error

For Umeå Building, the majority of items in the technical description have been able to be included in the calculations either by precise weight from the manufacturer or by an assumed weight. The few exceptions were an external cistern to a toilet, an x-branch in mineral wool and valves, as seen in Appendix B. The cistern and the x-branch should not have been a large contributor to the total impact as these are generally relatively light weight pieces compared to other products in these HVAC systems, and they were only one piece each. The valves are more difficult to estimate how the lack of data and therefore exclusion from the impact has affected the results.

The assumption that is deemed to have had the largest effect on the results is how the volume calculations for the pipelines, ventilation ducts and their connected parts were carried out. Had data regarding weight been more accessible the results would have been sounder. Other assumptions like the choice of impact assessment method, for the Ecoinvent data, and the 25% add on for the material content data were shown in Section 4.6 to have little effect on the end results.

A possible source of error for the results is deemed to be the human factor. Since the data has been very difficult to manage there is a risk that some data has been either misinterpreted or lost in the process. Although, since the results are deemed to be reasonable the human factor is not deemed to have had a major effect.

5.7 Difficulties in processing data and data gaps

The report has identified difficulties in collecting information necessary to perform the calculations and what the state of the art regarding EPD´s, generic data and material data is. The most time-consuming part of this project has been the search for information on weight and material content of the products listed in the technical description and the BoM-lists. Through this project it has become obvious that the calculation of the climate impact would be much quicker and easier if this information was included in the BIM-model.

Another difficulty identified was the lack of EPD´s. 28% of impact from Umeå Building was calculated based on EPD’s. The majority, 54%, of the impact of Umeå Building was calculated based on generic data. The remaining 18% was based on material data. What data the calculations are based on affects the certainty of the calculations. Specific data such as EPDs is a more accurate representation of the actual impact of the product and is a much more precise basis for the calculation.

Another issue has been data gaps in the BoM-list that complicated the process of calculating the climate impact. This has included the lack of information on manufacturer and product model name, etc. This meant that more time had to be put into finding hypothetical manufacturers, which was also based on assumptions. Had these types of data been included in the BoM-list the process would have been faster and more accurate.

How user friendly the BoM-lists were to calculate the climate impact was also dependent on which type of model they were extracted from. Data extracted from Solibri was less structured than data extracted from MagiCAD and thereby increased the risk of human error in the calculations.

5.8 Limitations

The limitations of the report have had an impact on the results. One of the most prominent limitations has been to only look at building part 84 (SH) and 85 (CV) and thereby exclude the remaining parts from building part 8. Had building part 86 (Electrical installations), 87 (Transport) and 88 (Control and automation) also been included a result from the entire HVAC system could have been presented. This limitation was deemed to be necessary to calculate a result within the timeframe of the study.

The choice to only study the life cycle phases A1-A5.1 has also had a significant impact on the results. Had a full LCA been carried out, all of the life cycle stages of the HVAC system in the building would have had to be examined. These limitations were however deemed necessary due to the time limit of the study. The time limit combined with the climate declaration only including life cycle phase A made these limitations reasonable.

Since both buildings are located in Sweden it would have been preferable to only use the Swedish database for generic data. However, since the Swedish database by Boverket did not have any specific HVAC products included, it was necessary to use the Finnish database CO2data.fi. Different countries can have different climates and cultures which affect the design of buildings. This means that it is not always possible to use databases for generic data from another country. For products in the HVAC system however, the data in the Finnish database was deemed applicable since it was the products in themselves that were studied.

The report has studied a specific type of building, university buildings, and the results are therefore not representative of other types of buildings. This limitation complicates the comparison of the results to other types of buildings as university buildings have specific and varied needs, as illustrated by the descriptions of the buildings in Section 1.4.

6 Conclusion

The aim of the report was to calculate the climate impact of the HVAC systems of Umeå Building and Nya Konst, which was achieved. The results show that the climate impact of the HVAC systems for the studied buildings are similar to each other. They are also very close to the reference values that they are compared to. The calculated values are deemed to be reasonable.

The issues with the calculations that were identified can potentially be solved by having the information on material content and weight of products in the models or in the technical description, and by companies providing EPD’s for their products. With these suggestions the calculations would be faster, and the results would be more certain as the climate data would be more specific. Having the information on weight and material content available in this way would also decrease the risk of human error in the method.

A potential to simplify the calculations for future studies was identified. By only calculating the six product groups with the largest climate impact it would speed up the method by far. For Umeå Building this would correspond to 81% of the HVAC systems total impact (73% if connecting parts for PNU and QLB/QLC are excluded). If the process were faster more calculations could be performed by more actors, which also could put pressure on more actors to provide EPDs on their products.

It can be concluded that calculating the climate impact from Project planning documents can be facilitated by having a reference building similar to the building being calculated. The reference building can be used to draw assumptions from to receive a more certain result. Without the reference building it can be hard to achieve a high enough coverage rate to have a solid result, as the Project planning documents have not yet solidified all plans for the building. If the six product groups that were identified in the hotspot analysis are also designed with a high detail level in the Project planning stage, that would increase the potential to calculate the climate impact of the HVAC system with a greater certainty earlier in the process.

To conclude it is recommended that more research is carried out regarding the climate impact of HVAC systems on more types of buildings, as the result of this report is very specified to this type of university buildings. This would increase the general knowledge regarding the GHG emissions from HVAC systems in the production and construction phase.

7 Reference list

Akademiska Hus. (2021). *Startskott för ny byggnad vid Umeå universitet*. https://www.akademiskahus.se/aktuellt/nyheter/2022/11/startskott-for-ny-byggnad-vid-umea-universitet/

Akademiska Hus. (2023a). *About Akademiska Hus*. https://www.akademiskahus.se/en/about-us/about-akademiska-hus/

Akademiska Hus. (2023b). *Hur går byggprocessen till?* https://www.akademiskahus.se/om-oss/vanliga-fragor/hur-gar-byggprocessen-till/

Akademiska Hus. (2023c). *Ny byggnad för Konstnärliga fakulteten*. https://www.akademiskahus.se/vara-kunskapsmiljoer/byggprojekt/vara-byggprojekt/goteborg/konstnarliga-fakulteten/

Akademiska Hus. (2023d). *Vår verksamhet*. Akademiska Hus. https://www.akademiskahus.se/om-oss/var-verksamhet/

Akademiska Hus. (2023e). *Vi bygger hållbart*. https://www.akademiskahus.se/vara-kunskapsmiljoer/byggprojekt/vi-bygger-hallbart/

Akademiska Hus. (2023f, June 20). *Akademiska Hus invests billions in central Gothenburg*. https://www.akademiskahus.se/en/news/news-room/2022/06/akademiska-hus-invests-billions-in-central-gothenburg/

Baumann, H., & Tillman, A.-M. (2003). *The Hitch Hiker's Guide to LCA : an orientation in life cycle assessment methodology and application*.

Boverket. (2021, September 30). *Klimatdeklarationens omfattning*. Boverket. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/omfattning/

Boverket. (2022a, May 18). *Klimatdata till beräkningen*. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/underlag/klimatdata-till-berakningen/

Boverket. (2022b, May 18). *Täckningsgraden ska beräknas*. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/berakna/tackningsgraden-ska-beraknas/

Boverket. (2022c, May 18). *Underlag till beräkning av klimatpåverkan*. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/underlag/

Boverket. (2022d, May 19). *Indata om transport i byggproduktionsskedet*. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/underlag/indata-transport/

Boverket. (2022e, May 20). *Sök i Boverkets klimatdatabas*. Boverket. https://www.boverket.se/sv/klimatdeklaration/klimatdatabas/klimatdatabas/

Boverket. (2022f, August 18). *Byggdelar som ingår*. Boverket. https://www.boverket.se/sv/klimatdeklaration/gor-sa-har/byggdelar-som-ingar/

Boverket. (2023a, January 9). *Utsläpp av växthusgaser från bygg- och fastighetssektorn*. Boverket. https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/miljoindikatorer---aktuell-status/vaxthusgaser/

Boverket. (2023b, January 24). *Om Boverkets klimatdatabas*. Boverket. https://www.boverket.se/sv/klimatdeklaration/klimatdatabas/om-klimatdatabas/

Calderon, R., Löfås, P., & Larsson, A. (2022). *Klimatarbete Hoppet Delrapportering 2 Byggskede*.

Christina Kiamili, A. (2020). *Detailed assessment of embodied carbon of HVAC systems for a new office building based on BIM*.

Enebjörk, A., Uskali, D., & Winqvist, E. (2022). *Klimatpåverkan av installationssystem i byggnader*. https://www.sbuf.se/projektresultat/projekt?id=92ad568a-303a-4058-9869-45f644438468#:~:text=Med%20av%20avgr%C3%A4nsning%20f%C3%B6r%20modul%20A1%2DA3.&text=storleksordning%20som%20data%20fr%C3%A5n%20andra,tv%C3%A5%20kontorsprojekten%20varierar%20klimatp%C3%A5verkan%20mycket.

Energimyndigheten. (2010). *Kommunala energiindikatorer*. https://energimyndigheten.a-w2m.se/ResourceComment.mvc?resourceId=104258

Energy Agency, I., & Nations Environment Programme, U. (2020). *GlobalABC Roadmap for Buildings and Construction Towards a zero-emission, efficient, and resilient buildings and construction sector*. www.iea.org

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (2018). *Life Cycle Assessment: Theory and Practice*. https://doi.org/10.1007/978-3-319-56475-3

IVL Svenska Miljöinstitutet. (2022a). *10. Schabloner för vissa byggdelar*. https://www.ivl.se/projektwebbar/klimatkrav-till-rimlig-kostnad/anvisningar-lca-berakning-byggprojekt.html

IVL Svenska Miljöinstitutet. (2022b). *11. Schabloner för byggarbetsplatsen A5.2-A5.5*. https://www.ivl.se/projektwebbar/klimatkrav-till-rimlig-kostnad/anvisningar-lca-berakning-byggprojekt.html

Kiamili, C., Hollberg, A., & Habert, G. (2020). Detailed assessment of embodied carbon of HVAC systems for a new office building based on BIM. *Sustainability (Switzerland)*, *12*(8). https://doi.org/10.3390/SU12083372

Lappalainen, P. (2021). *Klimatpåverkan av VVS-installationer*. www.kyh.se

Malmqvist, T., Borgström, S., Brismark, J., & Erlandsson, M. (2023). *Referensvärden för klimatpåverkan vid uppförande av byggnader. Version 2, 2023*.

Malmqvist, T., Borgström, Sara., Brismark, Johanna., Erlandsson, Martin., & KTH Skolan för arkitektur och samhällsbyggnad (ABE). (2021). *Referensvärden för klimatpåverkan vid uppförande av byggnader*. KTH Skolan för Arkitektur och Samhällsbyggnad.

Moncaster, A. M., & Symons, K. E. (2013). A method and tool for “cradle to grave” embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards. *Energy and Buildings*, *66*, 514–523. https://doi.org/10.1016/j.enbuild.2013.07.046

OneClick LCA. (n.d.). *Impact Assessment Categories (CML, TRACI and PEF)*. OneClick LCA. Retrieved May 9, 2023, from https://oneclicklca.zendesk.com/hc/en-us/articles/360015036980-Impact-Assessment-Categories-CML-TRACI-and-PEF-

Skanska Kalkyl. (2014). *Reviderad upplaga Skanskas Byggdel (BSAB83)*.

Stigemyr Hill, V., & Borgström, S. (2022). *HS30 Klimatstöd Sammanställning av kunskapsläget för byggdel 7-invändiga ytskikt och rumskomplettering byggdel 8-installationer*.

Ylmén, P., Peñaloza, D., & Mjörnell, K. (2019). Life cycle assessment of an office building based on site-specific data. *Energies*, *12*(13). https://doi.org/10.3390/en12132588

Appendices

Appendix A - Assumptions

Stabil 54-210/430-1800 had a seated area of wood above the radiator. This part was calculated by assuming a depth and using the area of the radiator as a volume and assuming the density for “Planed timber, u 16 %, coniferous” on Boverket. The weight was den calculated as a percentile for the entire product and from there on the calculations were done according to the method. For washbasins and WC the weight was assumed by using the EPD by Ifö.

Appendix B - Exclusions Umeå Building

Product/material	Reason for exclusion
Kitchen sink	In the material specification there was no way of determining what type of sink it was and it is most likely picked up in building part 7 with the appliances
Dishwasher	Included in building part 7 and the HVAC pipes connected to it is however included in the pipelines section.
Coffee machine	For the climate impact of HVAC systems, it is assumed to only include the valves that are connected to the coffee machine.
Extern cistern	No data on weight or climate impact data could be found.
Shut-off valves	No data on weight or climate impact data could be found.
Manual control valves	No data on weight or climate impact data could be found.
X-branch in mineral wool	Such a product did not exist
Wells in stainless steel	No data on weight could be found.

Appendix C - Materials assumed

Material used	Material assumed and used for calculations	Source
Hot-dip galvanized steel plate	Steel profile and grill, light-weight, galvanized	CO2data.fi
Aluzink AZ185	Aluminiumprofiler, primär	Boverket
Cold rolled steel sheet	Rostfri plåt, 65 % skrotbaserad	Boverket
Aluminum	Aluminiumprofiler, primär	Boverket
Plastic	polyethylene, high density, granulate, row 7017	Ecoinvent 3.8
Die-cast aluminium	Aluminiumprofiler, primär	Boverket
galvanized steel plate	Steel profile and grill, light-weight, galvanized	CO2data.fi
Perforated steel plate	Steel profile and grill, light-weight, galvanized	CO2data.fi
Steel	steel, unalloyed, row 5814	Ecoinvent 3.8
Copper	Kopparplåt, 51 % skrotbaserad	Boverket
Polystyren	polystyrene, general purpose, row 5605	Ecoinvent 3.8
Polyethylene	polyethylene, high density, granulate, row 7008	Ecoinvent 3.8
Carbon steel (kolstål)	steel, unalloyed, row 5814	Ecoinvent 3.8
Stainless steel	Rostfri plåt, 65 % skrotbaserad	Boverket
Ductile iron (segjärn)	Cast iron, row 1968	Ecoinvent 3.8
Cast iron	Cast iron, row 1968	Ecoinvent 3.8
Iron	Cast iron, row 1968	Ecoinvent 3.8
Polypropen (PP)	polypropylene, granulate, row 7017	Ecoinvent 3.8
Bronze	Bronze, row 8788	Ecoinvent 3.8
Brass	Brass, row 15829	Ecoinvent 3.8
Electronic	electronics, for control units, row 14033	Ecoinvent 3.8
Iron	Cast iron, row 1968	Ecoinvent 3.8
Galvanized steel	Steel profile and grill, light-weight, galvanized	CO2data.fi
Steel plate	steel, unalloyed, row 5814	Ecoinvent 3.8
PVC coated steel	Rostfri plåt, 65 % skrotbaserad	Boverket
Zinc	Zinc, row 17462	Ecoinvent 3.8
Zinc alloy	Zinc, row 17462	Ecoinvent 3.8
Thermoplastic	polypropylene, granulate, row 7017	Ecoinvent 3.8
ABS	ABS, row 2030	Ecoinvent 3.8

Appendix D - Volume calculations of the SH system from the BoM-list

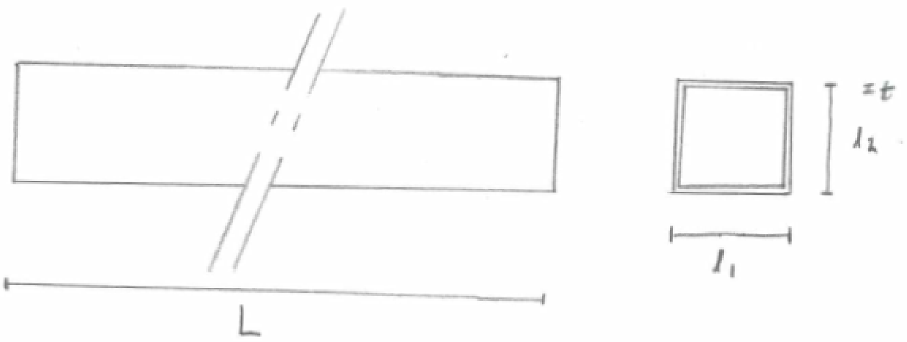
- The thickness of the reducer/expander, plug, bend, and t-branch were assumed to be the same as for the corresponding pipes. For t-branch and reducer/expander the thickness was assumed to be the same for the entire part and the same as a pipe for the thickest part.
- The bends are calculated as a full “donut” and the volume was multiplied with the specific angle in degrees and then divided by 360°.
- The reducer expander was calculated as a hollow cone with a 45° angle. Calculating the larger cone (with the base as the larger diameter) and subtracting the smaller cone (with the base as the smaller diameter).
- The t–branch was calculated by adding two hollow cylinders with the smaller one based in the center of the larger one.
- For the BoM-list of the SH system, the parts connecting the PEX and PAL pipes (X3 and X7) were assumed to be the pipes themself that had been bent to the wanted angle, therefore the same pipes had been used for all calculations.

Appendix E – Volume calculations for pipelines, ventilation ducts and their connecting parts

When conducting calculations for pipelines and circular ventilation ducts the cross-sectional area was calculated as for a hollow cylinder, the calculations presented picture illustrate cross-sectional areas for hollow rectangular blocks. Illustrations are the author's own.

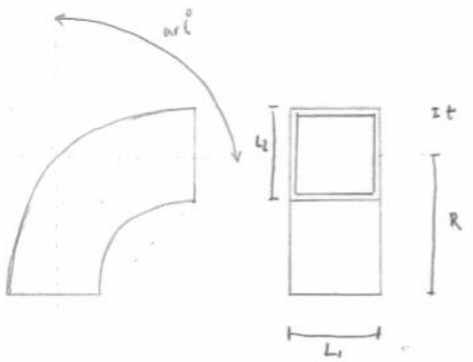
Pipelines and Vents/ducts

$$V = ((l_1 \cdot l_2) - ((l_1 - 2t) \cdot (l_2 - 2t))) \cdot L$$



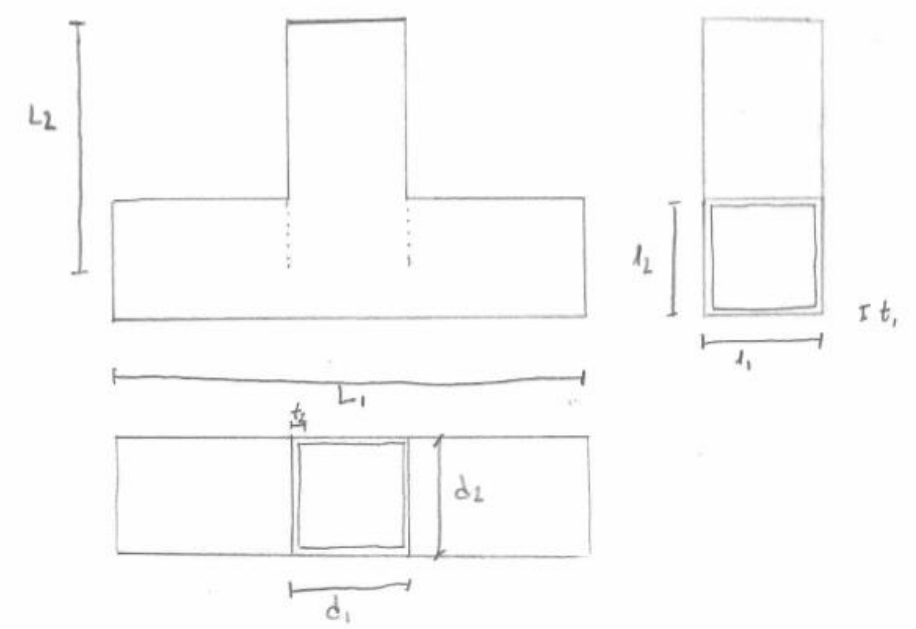
Bends

$$V = ((L_1 \cdot L_2) \cdot (2\pi R) - ((L_1 - 2t) \cdot (L_2 - 2t) \cdot (2\pi (R - 2t)) \cdot \frac{arc^\circ}{360^\circ}$$



T-branches

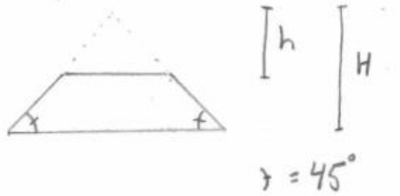
$$V = ((l_1 \cdot l_2) - ((l_1 - 2t_1) \cdot (l_2 - 2t_1))) \cdot L_1 +$$
$$+ ((d_1 \cdot d_2) - ((d_1 - 2t_2) \cdot (d_2 - 2t_2))) \cdot L_2$$

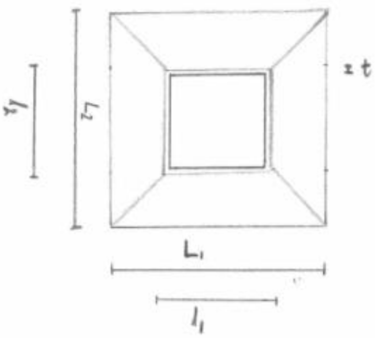


Reducer/expander

$$V = \left(L_1 \cdot L_2 \cdot H \cdot \tfrac{1}{3}\right) - \left((L_1 - 2t) \cdot (L_2 - 2t) \cdot (H - t) \cdot \tfrac{1}{3} \right) -$$

$$- \left(l_1 \cdot l_2 \cdot h \cdot \tfrac{1}{3}\right) - \left((l_1 - 2t) \cdot (l_2 - 2t) \cdot (h - t) \cdot \tfrac{1}{3} \right)$$





$$H = \sqrt{(L_1/2)^2 + (L_2/2)^2}$$

$$h = \sqrt{(l_1/2)^2 + (l_2/2)^2}$$

Appendix F – Assumed manufacturers

Pipelines and their connections

Material	Product code	Manufacturer
Copper	K2	Gebrit
Stainless steel	R2	Gebrit
Galvanized steel	S13	Gebrit
Steel	S4	Ahlsell
PE	E10	Geberit
Cast iron	G3	Gustavsberg
PP	P2	Pipelife
PP	P3	Uponor
PP	P5	Wavin
Stainless steel	R3	Geberit
PEX	X3	LK systems
PEX	X7	LK systems

Ventilation ducts

For the products in galvanized steel Lindab was assumed to be the manufacturer. For the ventilation ducts in mineral wool, the manufacturer was assumed to be Climate recovery.

Appendix G - Volume calculations of the CV systems from the BoM-list

- The volume of the mineral wool reducer expanders was calculated the same way as the pipes, as a hollow cone with a 45° angle. Calculating the larger cone (with the base as the larger diameter) and subtracting the smaller cone (with the base as the smaller diameter).
- The volume of the plugs was calculated by taking the cross-sectional area multiplied by an assumed thickness of 9 mm based on product data sheets.
- The volume of the rectangular reducer/expander was calculated as a hollow pyramid. Calculating the volume of the larger pyramid (with the base as the larger rectangle) and subtracting the volume of the smaller pyramid (with the base as the smaller rectangle).
- The rectangular bends were calculated similarly to the pipe-bends, as a "donut" but with a rectangular cross-section. The full volume of the donut was then multiplied with the angle of the bend in degrees divided by 360°.
- The volume of the rectangular X- and T-branches was calculated by simply subtracting the cross-sectional area of the "branch" from the surface area of the duct. The thickness of the galvanized steel for the bends, X- and T-branches volume calculations was assumed to be 1 mm based on product data sheets.
- The mineral wool ducts were calculated in m^2 surface area along with the provided thicknesses in the technical description.

Assumptions related to calculations of the CV systems from the BoM-list.

- Thicknesses of the products in galvanized steel were assumed through studying product datasheets.
- Blacksheet steel was assumed to be galvanized steel due to lack of information on the weight of blacksheet steel.
- Reducer/expanders that went from circular to rectangular were assumed to be rectangular to rectangular to not underestimate GHG emissions.
- "Glass wool, bats and rolls" from Boverket´s database was assumed to be the type of mineral wool used for the calculation of the impact of the mineral wool reducer/expanders.
- Some sizes on bends and t-branches did not exist and was assumed to be the closest bigger size, to not underestimate.
- For some angles of circular bends, data on weight could not be found. Weight for those angles was then calculated as weight of closest larger angle * (angle/closest larger angle).
- For mineral wool bends data could only be found in Prodikt for the 90-degree bends and the other angles were therefore calculated by percentage of the weight of the 90-degree bend: weight of 90-degree angle * (angle/90)
- Some larger dimensions of rectangular ducts did not have a weight. A factor for kg/m2 of surface area was therefore calculated based on the largest available dimensions and used to assume a weight for the larger dimensions that did not have a weight specified.

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