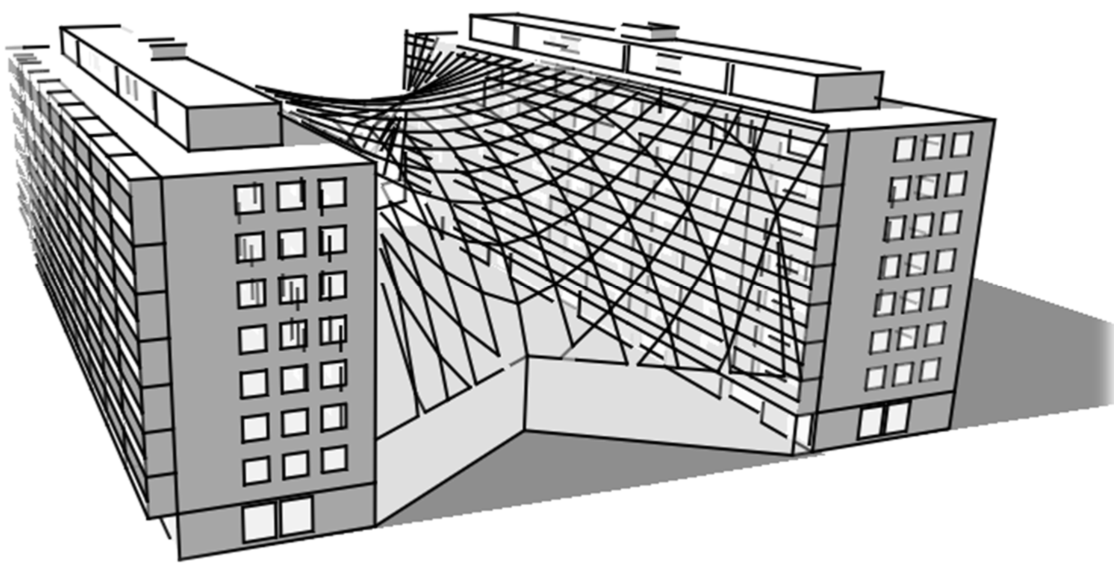
Life cycle assessment of EKO-Canopy renovation concept for Swedish Million Homes Programme



Technical University of Denmark

Preface

This master thesis is written as a cooperation between the center for Quantitative Sustainability Assessment and the center for Civil Engineering, both located at the Technical University of Denmark (DTU). Morten Birkved and Lotte Bjerregaard Jensen from DTU have been the main supervisors on the project. Elise Grosse from White Architects in Stockholm has been external partner on the project, and has contributed with information and supervision. The project represents 30 ECTS points and was carried out during a 5-month period from 23rd of January 2017. The report was handed in 23rd of June 2017. The project will be represented at Green Challenge 2017 at DTU, and is funded by the Nordic Built programme. I want to thank my supervisors Morten and Lotte for guidance and input throughout the whole project. I also want to thank Elise Grosse for providing me the opportunity to work at the White office in Stockholm, and providing me with information about the EKO-canopy concept. Lastly, thanks to Magnus Byberg and Mikkel Kirkeskov Knudsen for helping me collect data, information and drawings.

Author:

Rune Andersen, s123684

Kgs. Lyngby, Denmark

23rd of June 2017

NORDIC BUILT

DTU Civil Engineering
Department of Civil Engineering

Quantitative Sustainability Assessment
Department of Management Engineering

white

Abstract

The main goal of this master thesis study is to investigate an alternative renovation strategy for the Swedish Million Homes Programme, which applies an ETFE canopy to the construction. The idea is that the canopy will reduce the energy consumption of the building, while renovation of all facades facing the canopy can be avoided. The study will investigate if there is a break-even point where the avoided impacts becomes larger than the impacts from the construction of the canopy. This was investigated with dynamic energy simulation in IDA ICE and dynamic large scale LCA studies in OpenLCA. The canopy used in this study is called an EKO-Canopy, and is a concept developed by White architects. Different canopy sizes will be compared with a traditional renovation normally used in buildings from the Swedish Million Homes Programme. All results are compared with four dynamic future scenarios for the Swedish energy mix and a single standard non-dynamic energy mix from the database.

The result of the energy performance of the building showed an annual saving in the electricity consumption for the canopy scenarios when compared to a traditional renovation. The electricity saving was related to the heat pump and the lower heat loads for the canopy scenarios. The results of the optimization of the canopy showed that an acceptable indoor temperature in the canopy can be obtained during the year using only passive systems.

The LCA study showed that much of the avoided impact for the facades will be related to the windows. The largest impact from the canopy was the ETFE materials, while the timber construction will contribute with a negative impact, due to the incineration of timber for production district heating in the end of life flows. The dynamic district heating had a large impact on the end of life flows where incineration was included in the process. The dynamic electricity mix had a large influence on the change in the annual impact in the different scenarios. The break-even point could be obtained in all canopy scenarios in all five impacts categories included in this study.

1. Introduction

1.1. Problem statement

Many of the buildings that were built during the Swedish Million Homes Programme in the period of 1965-1974 are now more than 40 years old, meaning that a major renovation should be carried out to optimize the buildings' energy performance and replace outdated building parts.

Research studies have shown that a glass canopy on buildings as a renovation concept can avoid some replacements of the building envelope and reduce the annual energy consumption for the building. This project will study different canopy concepts in relation to energy and material savings. The project will be based on a EKO-Canopy proposal made by White Architects in Stockholm.

The project will investigate the canopy concepts through dynamic LCA studies, and investigate whether there is a break-even point where the avoided environmental impact from building materials and energy are higher than the environmental impact from the construction of the canopy. Different canopy concepts will be investigated in terms of shape and area. The different canopy concepts will be compared with a traditional renovation where windows are replaced and new insulation and new claddings are added to all facades.

1.2. EKO-Canopy concept by White Architects

The EKO-Canopy concept by White Architects was developed for a Nordic innovation contest where the goal was to find innovative solutions for the use of residual heat in cities. The concept was to make a glass canopy that connects two apartment blocks. The new canopied area will then make a new semi-outdoor space that is protected from rain, snow and wind. The canopied area could then be used for small-scale agriculture based on aquaponic systems, which produces both vegetables and fish. The glass canopy will be warmed by the heat loss from the apartments and the solar radiation through the glass roof and gables. The water in the fish tanks and in small basins will act like heat storage tanks which absorb the heat during the day, and then emit it back to the canopy during the night to keep a stable temperature.

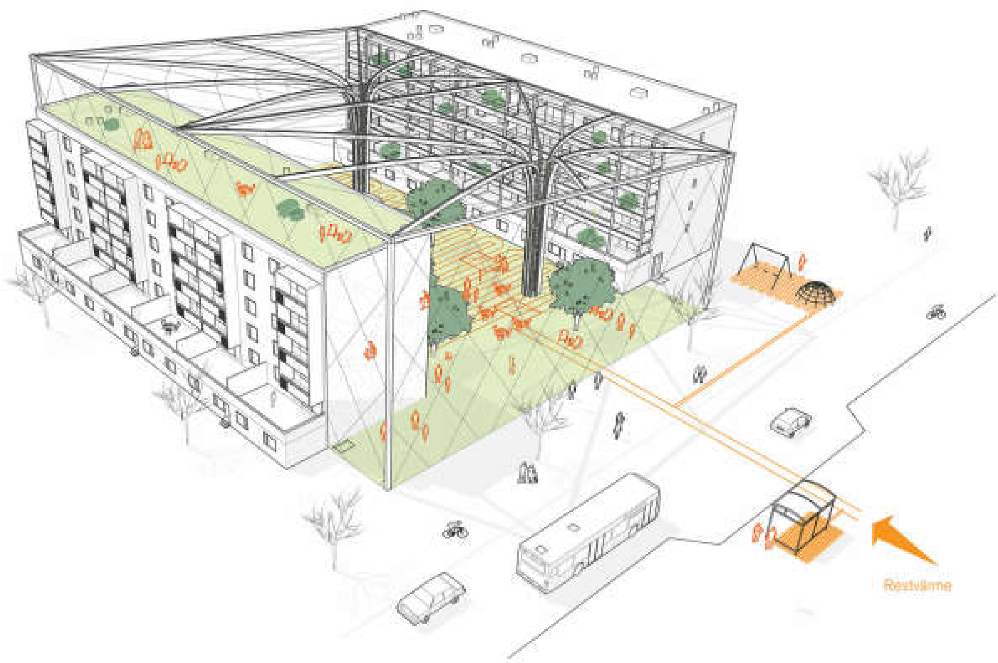


Figure 1.2.1 EKO-Canopy proposal by White Architects (Source: White)

Some of the roof will be covered by solar cells that both produces energy and act like solar shading to avoid overheating in the canopy. Rainwater from the roof will be collected and then used in the ponds and fish tanks in the canopy. The residual heat from the ponds will also be circulated in tubes placed in the ground. This will extend the growing season for the vegetables, and make a semi-outdoor space that can be used by the residents most of the year. With a glass canopy the energy loss from the apartments will be reduced, as the temperature difference for the facades facing the canopy is smaller. The facades will also be protected from the weather, which means that the facade materials get a longer lifetime.

1.3. Previous EKO-Canopy master thesis from DTU

Several EKO-canopy master theses have been carried out at DTU since 2015. One of the first EKO-Canopy master thesis at DTU was carried out from September 2015 to March 2016. The goal of the thesis was to investigate different EKO-Canopy solutions for renovation of buildings from the Swedish Million Homes Programme. The project was a case study of a renovation of Dragonvägen in Sweden, where different canopy layouts were compared in relation to snow and wind loads, energy consumption, indoor climate, daylight, geometry and material usage. The main result of the study was the development of an ETFE canopy based on a minimal surface. The ETFE structure is light compared with glass structures, while the curved shape of the minimal surface reduces the wind load, and allows snow to glide off the surface during winter. Another important finding in relation to the canopy was that the energy and indoor climate simulation of the canopy showed that the it could be heated and cooled using only passive means, but that high temperatures within the canopy should be expected during the summer (Knudsen, 2016).

Another master thesis was carried out at DTU in relation to the EKO-Canopy concept from January 2016 to June 2016. The goal of this thesis was to study integrated dynamic methods to minimize and optimize the structural construction of the canopy. The study was based on a squared glass canopy with the Rhino Grasshopper program. The main finding in the study related to the EKO-Canopy was the optimized structural system, which can be applied in future studies or development of the EKO-Canopy concept (Vila, 2016).

A master thesis from DTU, which is not directly connected to the EKO-Canopy but still worth mentioning, is a study about social sustainability, which was submitted in July 2016. The goal of the study was to investigate how social sustainability can be implemented and used in the early design phases of a renovation project. The case studies in the report were typical Nordic post-war social housing. Dragonvägen was used as a case study which makes the study relevant for this project. The case study was a renovation of the blocks without a canopy, but the concepts of social sustainability from the area will still be relevant in a EKO-canopy design process, and should be considered in future projects. The main finding relevant to this study was the proposal of opening the building in the lower levels to create new semi-private and public spaces, while getting lighter rooms, more flexibility and social awareness (Otovic, 2016).

2. Literature review

2.1. Renovation in the Swedish Million Homes Programme

The Swedish Million Homes Programme was a large construction project, launched by the Swedish government in the 1960s. The result of the program was around one million apartments, which were built in the period from 1965-1974. The Swedish Million Homes Programme includes a large variety of different housing forms such as single houses, row houses and larger apartment blocks (Hall & Vidén, 2005). The structure of the buildings was mainly based on pre-casted concrete slabs with bearing wall between the apartments. The facades can vary in materials from light wooden walls, with wooden or metal cladding, to heavier walls of bricks or sandwich concrete elements. (Kling, 2012).

The buildings in the Swedish Million Homes Programme had to be cheap and fast to build, which means that most of the buildings need a larger renovation today. Research from Sweden has shown that there is a large difference in the focus on energy efficiency in different renovation projects on buildings from Swedish Million Homes Programme (Högberg, Lind, & Grange, 2009).

One of the challenges with renovations of buildings from the Swedish Million Homes Programme is that many of the apartment blocks are located in areas which are populated by people with a lower income. If the renovations are too expensive, it will result in higher rents. Some of the residents will then be unable to move back to their apartments because they cannot afford the higher rent (Lind, Annadotter, Bjork, Hogberg, & Af Klintberg, 2016).

One solution that is used in the renovation projects is to give the residents the possibility to choose the extent of the interior renovation of the apartments. The residents can then choose between kitchens and bathrooms in different prize levels. This concept was also used in the renovation of the two blocks at Dragonvägen, which is the reason why some balconies there have a closed glazing facade, while others do not.

Another issue that must be handled when renovation buildings from the Swedish Million Homes Programme is the presence of asbestos and PCB in building parts. If these materials and chemicals are present in the building that is renovated, the price can become higher, and different safety actions for the construction works must be carried out. The building should therefore be investigated thoroughly before the renovation starts (Kling, 2012).

2.2. Future energy grid in Sweden

The share of different energy sources in the Swedish energy grid for both electricity and district heating will change in the future, due to new developments, different energy policy and user demands. It can be difficult to predict how the energy grid will look like in the future. The Swedish Energy Agency published a report in 2016 with 4 different scenarios for the future energy system in Sweden (Swedish Energy Agency, 2016). The scenarios will be driven by different motivational factors as low energy prices or focus on renewable energy. There will also be a variation in the amount of produced energy in the scenarios. Today Sweden has a large share of hydro power from river runoff. This energy form is relatively sustainable and cheap and will also be present in larger scale in the future energy mix.

2.2.1. Scenario Forte

The main driving force in the Forte scenario is to secure low energy prices. If the Swedish companies and industry have access to low price energy it will be possible to compete with companies in Asia and Africa on production cost. Another driven force is to make a grid that can provide a secure energy supply for the Swedish. Renewable energy is still a goal but economic growth is the top priority in the Forte scenario. Because of the low focus on climate and high focus on industry will this scenario have the highest energy consumption in 2050. The main energy sources will be hydro and nuclear power. The renewable energy part will only be around 50 % in 2050.

District heating energy production in TWh									
	Forte		Legato		Espressivo		Vivace		Reference
	2035	2050	2035	2050	2035	2050	2035	2050	2014
Bio mass	23	22	15	9	19	18	17	15	28
Peat	2	2	0	0	1	1	1	0	2
Waste	15	14	8	7	10	9	18	18	12
Waste heat	6	5	5	4	7	7	6	6	4
Oil	1	1	0	0	0	0	0	0	3
Coal	1	0	0	0	0	0	0	0	0
Natural gas	4	4	0	0	1	1	0	0	5
Coke	1	1	0	0	1	1	0	0	1
Heat pumps	7	7	6	4	8	8	10	3	5
Solar heating	0	0	0	0	2	2	0	0	0
Total	**59**	**55**	**34**	**23**	**49**	**46**	**51**	**42**	**59**
Losses	**8**	**7**	**5**	**3**	**8**	**8**	**10**	**8**	**13**

Figure 2.2.1 Forecast of dynamic Swedish district heating scenarios (source: The Swedish Energy Agency)

2.2.2. Scenario Legato

The focus areas in Legato is to reduce the global warming and get more ecological sustainability. Energy and resources will be considered as a global problem. Principles such as circular economy and a high rate of recycling of materials are top priorities, and many people are expected to move away from the cities to get a more simple and sustainable lifestyle in the countryside. More energy efficient buildings and industry through stricter requirements will also be a political focus. The main energy sources will be renewable energy such as solar, hydro power and biomass.

2.2.3. Scenario Espressivo

The Espressivo scenario is mainly focused around individual freedom and decentralization. Energy production will be on site or produced at local small-scale facilities. People will invest in their own energy production with the goal of being self-sufficient. This scenario will have the largest amount of small scale biomass and solar energy, both for heating and electricity, compared to the other scenarios.

Electrical energy production in TWh									
	Forte		Legato		Espressivo		Vivace		Reference
	2035	2050	2035	2050	2035	2050	2035	2050	2014
Nuclear power	84	69	0	0	34	3	26	0	62
Hydro power	69	70	63	55	60	60	65	68	63
CHP	21	25	11	9	16	17	24	35	13
Wind	15	10	50	70	20	25	30	50	11
Photovoltaic	1	2	10	12	25	30	10	22	0
Wave power	0	0	0	2	0	0	0	1	0
Small scale bio mass	0	0	0	0	0	10	0	0	0
Total	190	176	134	148	155	145	155	176	150
Losses	**12**	**11**	**10**	**10**	**10**	**14**	**9**	**12**	**11**
Export	**45**	**22**	**8**	**22**	**19**	**3**	**6**	**1**	**16**

Figure 2.2.2 Forecast of dynamic Swedish electricity scenarios (source: The Swedish Energy Agency)

2.2.4. Scenario Vivace

In the Vivace scenario, climate and green technology are the top focus. There will be a general opinion in the society that developing and introducing new green technologies will create new jobs and boost the Swedish economy. The energy system will be based on high tech production and will be used as a good platform for testing and development of future innovation technology. The energy production will be based on almost 100 % renewable energy in 2050.

2.3. Greenhouse living

There has been an increasing focus in the population on sustainable living within the last 10 years. But the concept of living inside a greenhouse or building a glass envelope over the house is not a new one. The Swedish Eco architect Bengt Warne was, in many ways, ahead of his time. He was very focused on ecological ways of living in houses that allowed the residents to live between water and plants.

In the early 1960s Bengt Warne designed a 250 m² prefabricated house called Water Lily House. The house was built in Sweden from 1962 to 1964, and was a light wooden house, with a large glass covered atrium that included an indoor swimming pool. Another house designed by Bengt Warne which is important to mention is the Nature house, which was built near Stockholm from 1974 to 1976. This house was once again based on a light wooden construction. The house was then covered by a glass envelope. The house was ventilated by a passive system as natural ventilation. Rain water from the roof was collected in tanks and used for showers, toilets, and laundry. The house was built on solid rocks that also act as thermal mass, which can obtain the radiated heat from the sun to avoid overheating during the day, and then emits the heat back to the room during the night (Sundby naturhus, 2014).

Figure 2.3.1 Uppgrenna Naturhus (2015) (Source: ArchDaily)

A group of Swedish companies have reinvented the Green house living concept and started to design a new nature house. The house is called Uppgrenna Naturhus and is designed in a collaboration between Tailor Made Architects and Darking as engineering consultants. The house was built in 2015 near Gränna in Sweden. The house is also based on a light wood construction with a large glass canopy. The temperate space underneath the canopy is used for growing vegetables and fruits. All waste water from toilets, dishwashing and laundry are circulated through the plant beds in the canopy, to clean the water and keep nutrients within the loop (ArchDaily, 2015).

Glass envelopes can also be used for larger projects. An example is Academy Mont Cenis Herne-Sodingen which is a university that is located within a 12960 m² glass envelope with a room height of 16 m. Large water canals within the building act as thermal mass to stabilize the indoor temperature. The structural construction is pure timber from local sources with steel connections. The roof and part of the facade have integrated photovoltaic panels that produce energy for the building and act as solar shading (Schlaich Bergermann Partner, 2000).

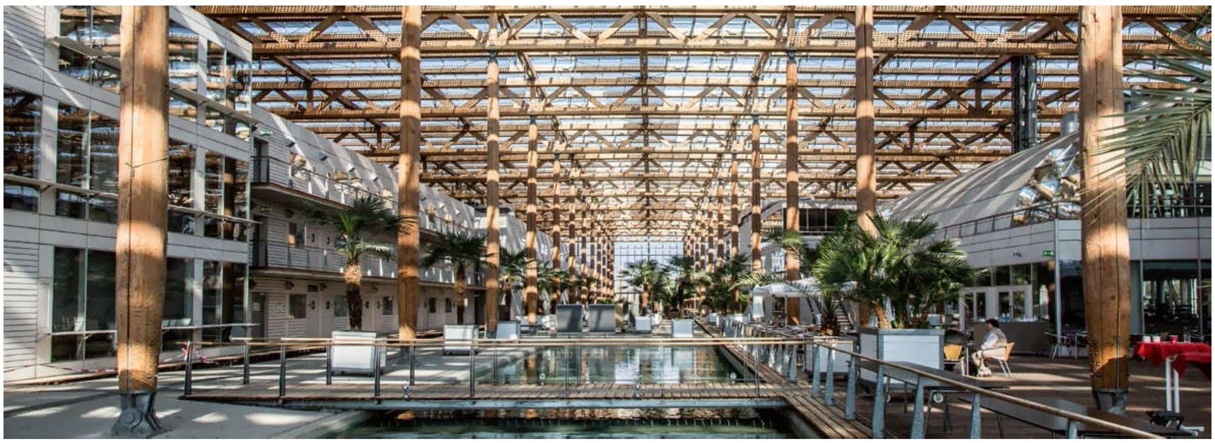


Figure 2.3.2 Glass covered room of Academy Mont Cenis Herne-Sodingen (Source: Nachrichten)

The Technical University of Denmark and The Royal Danish Academy of Fine Arts Schools of Architecture have carried out research on the benefits and disadvantages of placing buildings within a glass envelope. The research has shown that the glass envelope can reduce the necessary heating requirement. The building which was investigated was a 384 m² greenhouse, containing a building with an area of 62 m². The building consists of a light wooden construction with 225 mm insulation. The glass envelope is ventilated by natural ventilation, where up to 10 % of the glass roof can be opened.

The annual energy consumption of the house was investigated by dynamic simulations, both with and without the glass envelope. The results showed that the annual energy consumption for heating would be 43.5 kWh/m²/year. Reducing the volume of the greenhouse only had a very small influence on the energy consumption, but the total hours with overheating the greenhouse was reduced from 10 % of the time to 4 % of the time (Toftum, Petri, & Rønne, 2016).

2.4. Relation between materials and energy consumption

The environmental impacts from a building can normally be divided into the two categories: Building materials and operational energy use. The impacts from building materials can appear in all life phases of the building, while the operational energy use will appear only in the building phase. For an average Danish building the impact from the operational energy use is normally around 60 % of the total impacts from the building in relation to global warming potential.

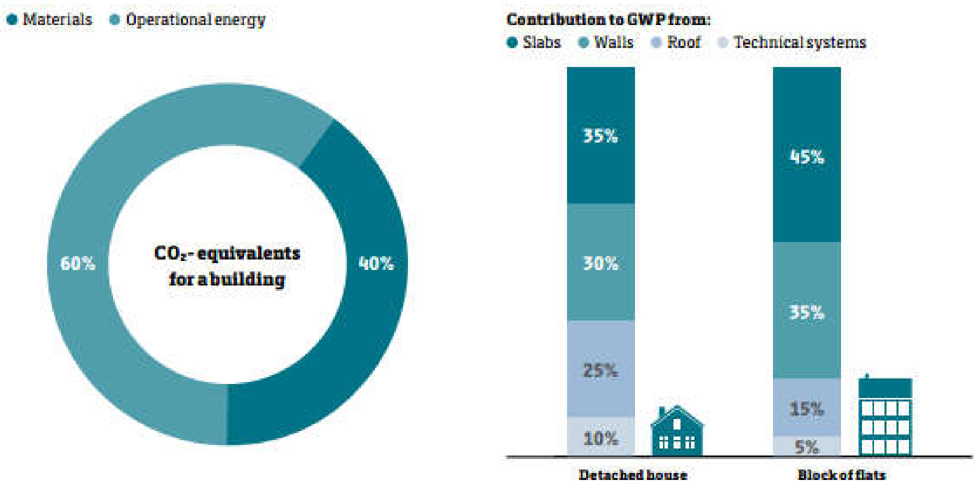


Figure 2.4.1 Distributions of impacts in typical Danish buildings (Birgisdóttir & Rasmussen, 2016)

New buildings have a lower energy consumption and higher insulation rates than older buildings. This means that the environmental impact from new buildings in relation to building materials will be larger than the impacts from the operational energy use (Birgisdóttir & Rasmussen, 2016).

Government regulation is mainly focused on the operational energy use in buildings. It is becoming harder and harder to optimize energy in buildings while the energy consumption becomes lower and lower. The focus is beginning to change from the operational energy use to the embodied energy in the building materials. These changes are mainly driven by national, EU, and international regulations (Birgisdottir, Mortensen, Hansen, & Aggerholm, 2013).

A study from DTU about the relation between insulation and dynamic district heating scenarios have shown that the high amounts of insulation in low energy buildings can cause a higher environment impact, because the district heating grid will have a lower impact in the future. The impacts from the insulations will then become higher than the annual avoided impact that can be obtained when building low energy houses with district heating (Sohn, Kalbar, Banta, & Birkved, 2016).

2.5. ETFE structures

2.5.1. What is ETFE?

The ETFE (ethylene tetrafluoroethylene) cushions systems is a transparent lightweight structure, where the transparent layers are made of thin ETFE film. The cushion can vary from 2 to 5 layers with a thickness of 80 to 300 μm that will give a total U-value in the interval of 2.94 to 1.18 W/(m²K), dependent on the number of layers (Hu, Chen, & Zhao, 2017). The ETFE layers are fixed in a metal frame that is self-supported. The cushions must be under constant pressure to ensure that the cushions do not collapse. The metal frame contains plastic tubes, also made of ETFE material, that blows air into the cushions. The air is blown from centrally placed stations. The pressure inside the cushion is normally kept in the range of 180 to 250 Pa. The energy use of the blowing station is around 60 W per 1000 m² of ETFE area (Gabi documentation, 2016).

According to Vector Foiltec, which produces the Texlon ETFE system, the ETFE material can be recycled 100 % into new plastic products in Europe. The ETFE material can only be recycled into new ETFE at factories in Germany. For the rest of the world, the ETFE is normally incinerated (Institut Bauen und Umwelt e.V., 2014).

Vector Foiltec has produced a product called Texlon PV (Photovoltaic). This is a thin 2nd generation photovoltaic (PV) cell based on a film structure. The PV cells' weight and thickness are not optimal for film cushion applications, because they are heavier than, for example, the 3rd generation PV cells. Another problem is that the effectiveness of the photovoltaic cell drops significantly then they are placed inside the cushion (Monticelli, Campioli, & Zanelli, 2009).

2.5.2. Advantages

One of the largest advantages of EFTE construction is the low weight. The metal frame can be produced from aluminum, which means that an ETFE construction can weigh 100-250 time less than other transparent constructions of glass (Hu, Chen, & Zhao, 2017). Another advantage is the high fire resistance caused by the fluorine in the material (Hu, Chen, & Zhao, 2017).

2.5.3. Disadvantages

One disadvantage of ETFE is that the cushions need total air pressure, which causes an energy consumption around 525.6 kWh per 1000 m² of ETFE per year. Another disadvantage is that the cushions can be punctured, making it difficult to use ETFE construction near the ground level.

2.5.4. Buildings with ETFE structures

Eden project – UK

Allianz Arena – Germany

Beijing National Aquatics Center – China

Palazzo Lombardia - Italy

2.6. Recycling of building materials

When there is materials replacement or demolition of buildings, it will result in a large amount of waste materials that needs to be handled. These materials can be reused, landfilled or incinerated. It is estimated that the construction industry is responsible for 31 % of all waste (Mortensen, Birgisdottir, & Aggerholm, 2015). There are in general three different types of recycling building materials, which is reuse, recycling and new applications. Reuse is when the building part are removed from a building, and the installed in another building. An example of materials with great potential for reuse is bricks, tiles or windows. Recycling is when the old materials from the construction are made into new materials, which normally is used for recycling of aluminum or steel. The new application is mostly incineration of materials for production of district heating or electricity. It can also be concrete that is crushed and used for road filling.

The opportunities for reuse of materials are highly dependent on the condition of the building part or material when it is removed from the building. There can be several reasons why the building components are removed. These reasons can often be linked to the four different lifetimes of building components. The first is the technical lifetime that is dependent on the condition of the component, and is decided by the time where the component cannot fulfill its purpose anymore. The second lifetime is the functional lifetime, which is based on the properties of the materials, and when it is outdated. The third lifetime is the economic lifetime, that is dependent on the time when the component becomes too expensive to maintain. The last is the aesthetic lifetime – data is based on changing in architectural styles (Aagaard, Brandt, Aggerholm, & Haugbølle, 2013). If a window is removed because it has reached the end of its aesthetic lifetime, can it still be functional and then reused in another building, which can give it another aesthetic expression and thereby a new lifetime. If the window is damaged and has reached its technical lifetime, is it not possible to reuse the window, so it must then be recycled instead.

A study has shown that recycling of materials in a high-rise building can save 53 % of the embodied energy in the materials second life, while reuse of materials will only save around 6 % of the embodied energy in the second life. The reason is that these high-rise buildings include a lot of steel, aluminum and concrete which have a good potential for recycling, but low potential for reusing due to structural requirements. Another finding was that doors and windows had a low potential for recycling, but that 48-50% of the embodied energy in windows and doors second life could be saved if window and doors is reused instead (Ng & Chau, 2015).

3. Theory and method

3.1. Scenarios

All scenarios in this study are based on buildings that are located at Dragonvägen in Upplands Väsby, Sweden. Specifically, 8 almost identical buildings that are placed in a row with around 35 m between them. The 2 buildings furthest south have been renovated, while the last 6 buildings have not, which makes the buildings optimal for comparison studies.

Figure 3.1.1 Facades of nonrenovated building. south (L) and north (R).

The external surfaces of the original building are generally in bad condition, with damaged facade cladding of aluminum and tiles. All facades have very little amount of insulation or none at all. All windows are 2-layer windows, with a metal covered wooden frame.

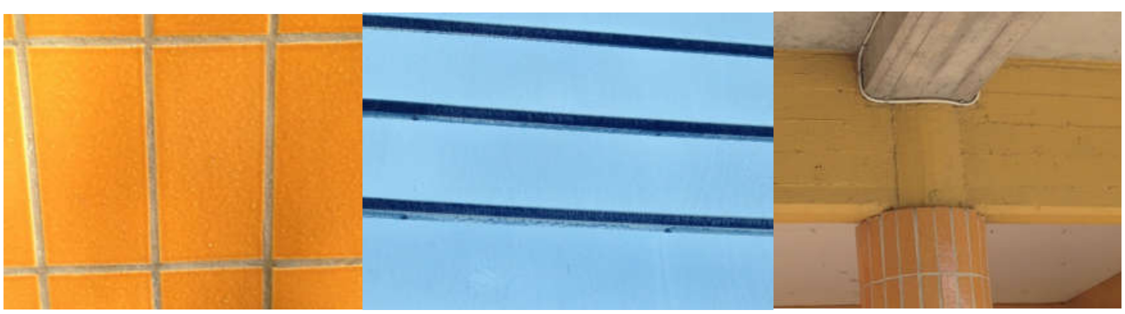


Figure 3.1.2 Dominating building materials: Tiles, aluminum and concrete

The structural system is based on load-bearing concrete walls in the gables and between the apartments, together with concrete slabs. The north and south facades are light wooden frame walls with mineral wool insulation. The roof is a typically constructed roof with both stone mineral wool and wooden fiber insulation. Heat sources for space heating and domestic hot water are supplied from district heating, with a heat exchanger located in the entry level. All apartments have extract ventilation from kitchens and bathrooms.

3.1.1. Reference renovation

The renovation of the two blocks was carried out by COBAB Sverige AB from October 2014 to June 2016 (COBAB, 2017). The renovation included reconstruction of all facades with extra insulation and establishing of new plaster facades. The old yellow tiles in the entry level were replaced with grey stone tiles. All windows in the apartments were changed to triple-layer glazing. The roof construction was not renovated. The aluminum facade cladding on the balconies was replaced with colored glass plates. The external wall between the apartment and the balcony was not renovated.

Figure 3.1.3 Facades of renovated building. south (L) and north (R).

All the stairways have been opened, allowing entrance from both sides of the building. The entrance to the building was widened with new windows and glass doors. All apartments have been completely refurbished with new surfaces, doors, installations, kitchens and bathrooms.

Figure 3.1.4 Dominating building materials: Tiles, facade plaster and glass

All ventilation ducts, fans and filters were also replaced. All ventilation ducts and heating pipes were insulated according to current requirements. A Thermia Vent unit is connected to the exhaust air from the ventilation system. The unit can extract the heat from the ventilation air, and transfer it to a liquid with high heat-conductive properties. The unit is then connected to a Thermia Vent heat pump. The recovered heat from the heat pump is then used for space heating and domestic hot water.

3.1.2. Scenario 1

The canopy in scenario 1 is the smallest canopy of the two canopy scenarios. The canopy is placed between the north and south facade of two building blocks. The canopy has a transparent envelope made of a 2-layer window system in the lower part of the gables, while rest of the envelope is made of a 4-layer ETFE cushion system that is tensioned between aluminum profiles. A large glued timber beam is placed in the middle of the canopy and connects the two gables. The aluminum profiles for the ETFE system will be attached to the facade and the timber beam. It is not possible to use the ETFE cushion system near the ground level, so the lowest 3 meters of the canopy will be window glazing that is supported by a wooden frame system. 313 m^2 of the canopy envelope will be covered by glazing while the rest 2896 m^2 of the envelope will be covered by the ETFE system.

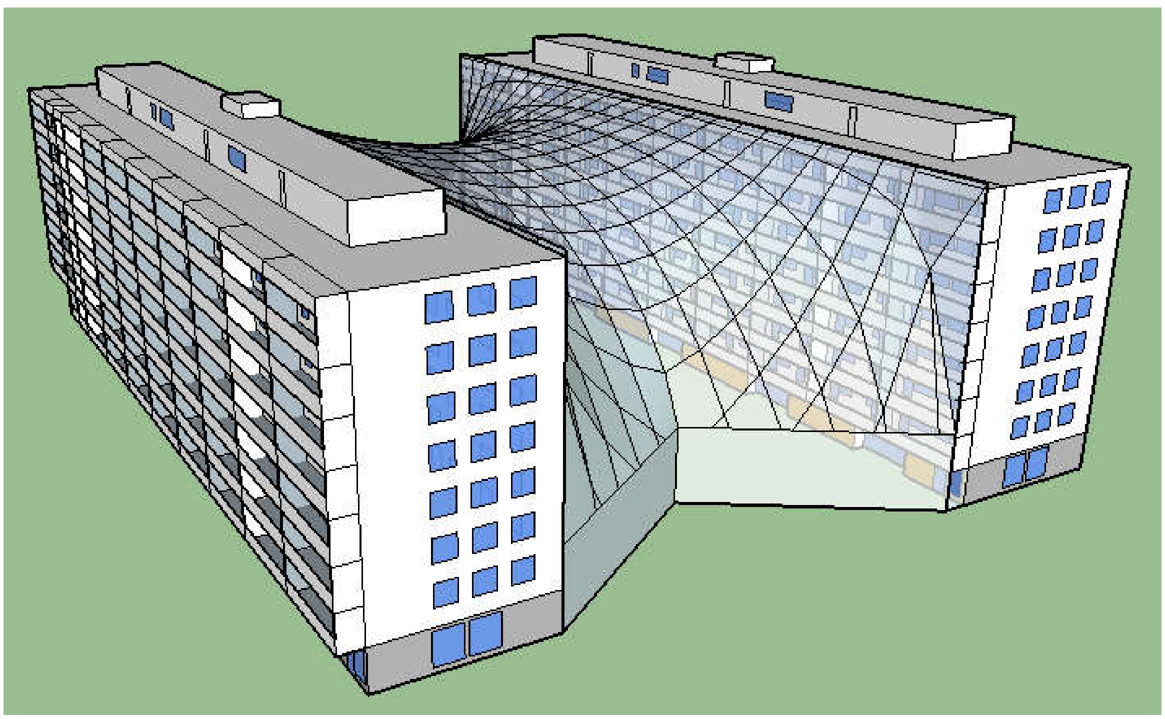


Figure 3.1.5 Canopy scenario 1

The inside of the building, including building system, will be renovated according to the reference renovation scenario. All building facades and windows, except the surfaces facing the canopy, will also be renovated as in the reference renovation scenario. The south facades with the balconies will be kept in same condition as the original building. A likely scenario is that the aluminum railing on the balconies is removed and replaced with a wooden railing. However, this is not included in this project.

It is assumed that the aluminum cladding on the northern building facade in the canopy is removed and replaced with a high-density glass wool plate with facade plaster. Furthermore, is it assumed that the entrance to the building also are renovated and widened with new windows and glass doors for the ground level facades facing the canopy.

3.1.3. Scenario 2

The canopy in the second scenario still covers the north and south facades. The main difference is that the canopy also covers all four gables of the building blocks. The canopy is extruded in the length of the building block. The glazing facade at the entry level has a smoother shape, so that the minimal surface design also can be applied at the gables.

All material composition is the same as in the first scenario, so the only differences in the canopies is the volume of the canopies and the amount of materials. The glazed area is increased to 688 m^2 while the ETFE area is increased to 4031 m^2.

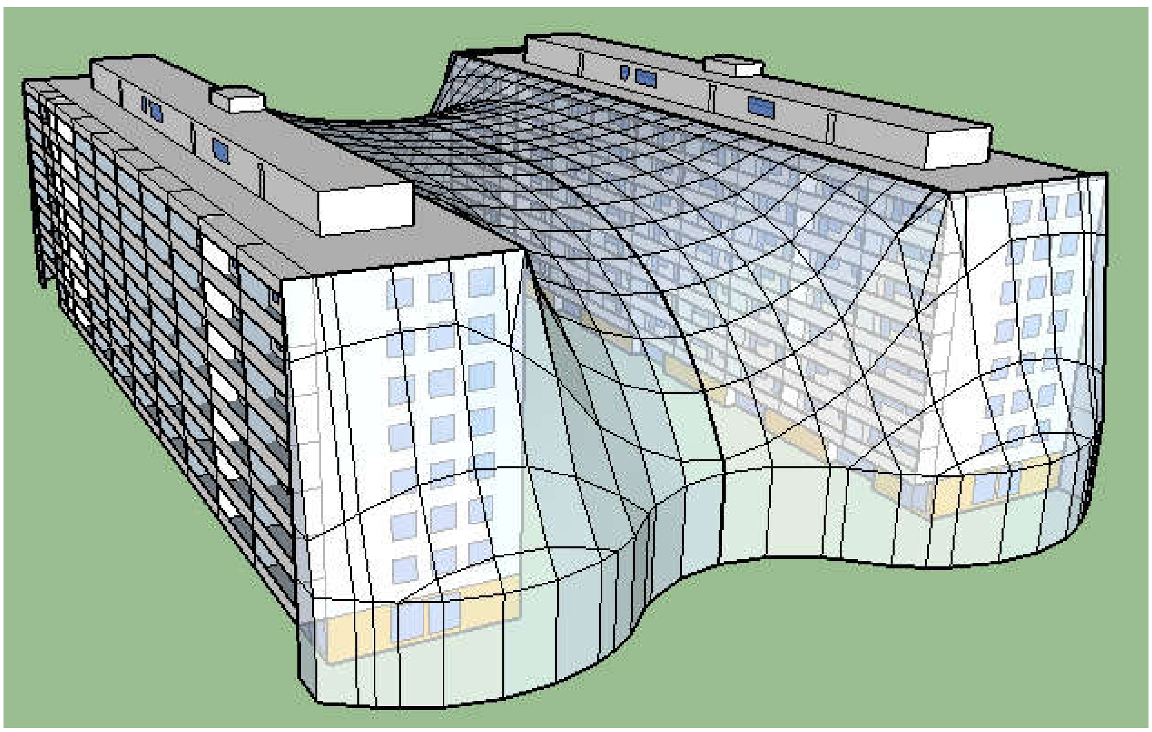


Figure 3.1.6 Canopy scenario 2

This approach avoids energy renovation of the gables, because they now are covered by the canopy. It is assumed that the upper metal cladding of the gables will be removed, and replaced with new facade plaster, as in the standard renovation scenario. The yellow tiles on the ground facade will not be changed, but broken tiles will be replaced.

It is possible that the lower ground levels facing the canopy will be opened, so that the basement in the ground level can be an integrated part of the canopy. The scenario with the open basement is not covered in this report, but could be a design proposal in a future canopy design process.

Both canopies will have natural ventilation, and the same internal use as suggested in the White EKO-Canopy design proposal, with common areas, water ponds and urban farming.

3.2. IDA ICE Dynamic building energy simulations

About the program

The program used for dynamic energy simulation is IDA ICE. The program was developed by a Swedish company called EQUA Simulation AB. The program can be used for making both energy and indoor climate simulations. The program can also be used for dimensioning and optimization of the building systems. The purpose of the simulation was to find the yearly delivered energy in relation to electricity and district heating. However, it is important to include the indoor climate in the investigation, to make sure that the building systems and the canopy behaves realistically.

All input data for the IDA ICE models can be found in appendix A.

3.2.1. Location, orientation and weather

The real buildings from the case study are located in the center of Upplands Väsby. The city is located around 20 km south of Arlanda Airport. Arlanda is therefore entered as the location in IDA ICE. The location in the program is mainly used for design conditions for heating and cooling load. The buildings are rotated in the program so the balconies are orientated towards south.

The weather file used in the program is a standard ASHRAE International Weather for Energy Calculation 2 (IWEC2) file. The weather file is valid for the Stockholm-Arlanda area.

3.2.2. Geometry

The entry level is specified as a basement on drawing of the building. This floor is only used for storage room, staircases, and technical room for heating installations. It is assumed that the basement is not heated, and will not be a part of the heated floor area. The same conditions are applied to the top penthouse, which is mainly used as technical room for the ventilation system, storage and common rooms.

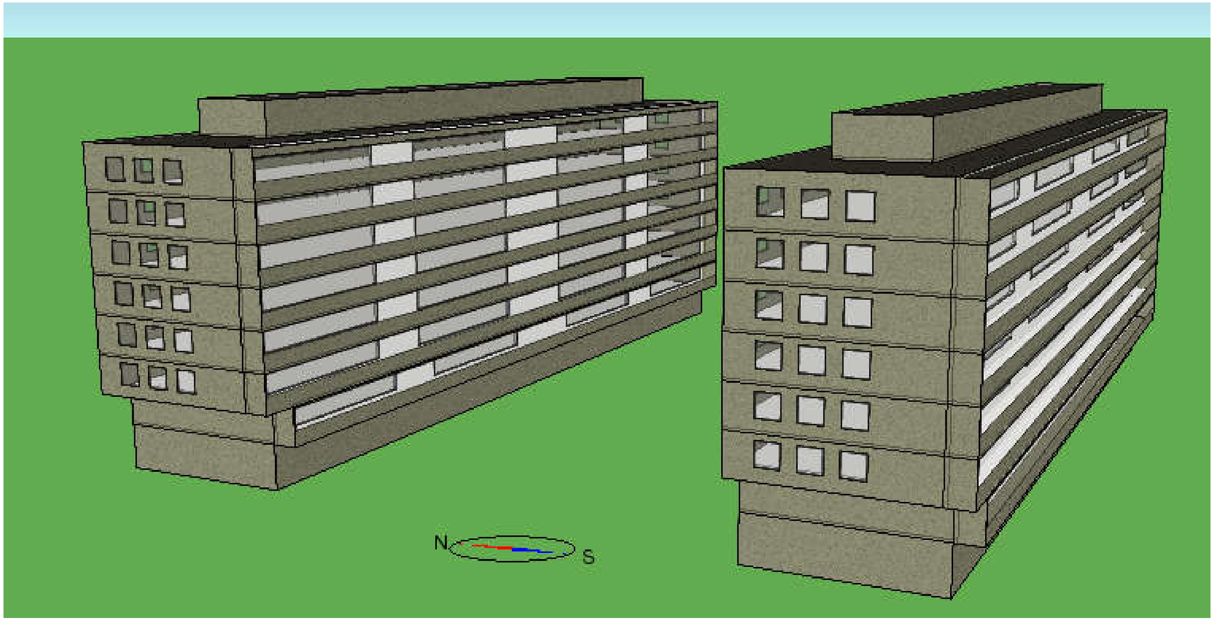


Figure 3.2.1 Building model in IDA ICE

The rest of the floors are mostly identical. The 1st floor is slightly shorter than the rest of the floors. Each floor is modelled as one large room. The balconies are made as an adjacent room with a wide opening in the external wall towards south. The windows between the apartment floors and the balconies are modelled as internal windows, but have the same properties as the external windows in the rest of the facades. All the dimensions of the model are based on the drawings that can be found in appendix B.

3.2.3. Building envelope

All construction is modelled in IDA ICE. The U-values for the different constructions are calculated in the program. The structure of the construction is based on drawings and descriptions. Both original and renovated constructions were modeled and then saved in the database. The renovated constructions are used as defaults in the program. For simulation with the canopy, all constructions facing the canopy are replaced with the old original constructions.

It has not been possible to find the real properties for windows used in the building. Windows in the simulation model are based on reference 2- and 3-layer windows from IDA ICE database.

3.2.4. Systems and internal gains

The building has a water based central heating system. The heating is provided by district heating and an exhaust air heat pump. There is no data on the number and capacity of radiators, so each floor has an ideal heater with an assumed heating power of 15 kW. It was not possible to connect the exhaust air heat pump to the ventilation system without starting an advanced model. The heating unit used in the model is an Thermia Mega brine to water heat pump with a heating capacity of 104 kW and a COP of 4.71. The fixed temperature supply for the heat pump is 20 °C, which is close to the air temperature of the exhaust ventilation. The setpoint for room heating is 21 °C, so the exhaust air temperature will not be below 21 °C most of the time.

There is only CAV (constant air volume) exhaust ventilation in the building, so fresh air is supplied through the facades. Polluted air is extracted from bathrooms and kitchens with a ventilation rate of 0.4 l/s per m^2.

Lighting is assumed to have an input of 2 W/m^2. No daylight simulation has been performed to investigated the right amount of lighting. The building systems in the apartments are very simple, so internal gains from equipment is not included in the model.

There are, on average, 10 apartments with 2 bedrooms on each floor in the existing building. Some of the apartments are occupied by families, and some of them are only occupied by a single person. It is therefore assumed that the average number of occupants on each floor is 20, which gives 140 occupants per block.

3.2.5. Canopy

3.2.5.1. Scenario 1 canopy

The canopy in the project has a smooth curved minimal surface. IDA ICE does not offer the possibility to model the same geometry. It is important for the final results that the indoor climate in the canopy behaves like in the design proposal. The internal volumes and the outer transparent area should therefore match the design proposal. This is obtained by making one large room that is sloped towards the middle of the canopy. The gables are also pulled into the middle like the design proposal. The surfaces of the canopy are not curved like the design proposal, but the envelope areas are close the proposal, so it can be assumed that it gives a more realistic result of the conditions in the canopy.

The canopy was optimized in the IDA ICE model several times, to obtain a canopy surface area that is close to the minimal surface, which is used for the alternative canopy renovation proposal. Table 3.2.1 shows the final areas of the simulated canopy scenario 1 in relation to the minimal surface area in the renovation proposal.

Table 3.2.1 Resulting transparent area of the simulated canopy scenario 1

	Glass area	**ETFE area**
Scenario 1 canopy minimal surface	313 m^2	2896 m^2
Scenario 1 canopy simulated	221 m^2	3065 m^2

The lowest 3 meters of the gables are 2-layer glass windows. Rest of the areas are covered by 4-layer ETFE. The ground is modelled as a 1 m thick layer of soil. The rest of the construction is modelled as 100 mm wooden walls.

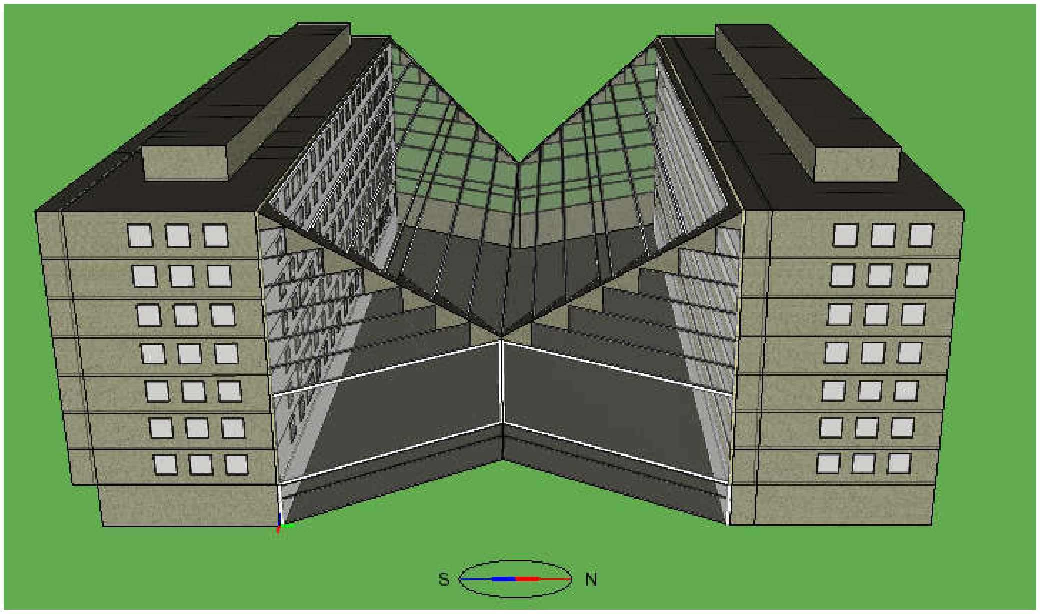


Figure 3.2.2 Scenario 1 IDA ICE model with canopy

The canopy is ventilated by natural ventilation through the windows and the roof. Each canopy gable has an opening area of 36 m². The roof has a total opening area of 120 m².

The canopy has no active systems. The program can only show the simulated indoor climate in rooms that are occupied, so a single person has been placed in the canopy.

The canopy in the design proposal contained water ponds and tanks that are to be used for hydroponic farming. 100 m³ of water is inserted in the canopy as internal mass in the program.

3.2.5.2. Scenario 2 canopy

The canopy in case 2 is covering the four gables of the building blocks. Additionally, the main canopy part is extruded in length so that it matches the canopy walls in the gables. In reality, will the canopy gables be sloped towards the ground. Due to limitations in the program, the canopy gables are simplified, so they are vertical instead.

Table 3.2.2 Resulting transparent area of the simulated canopy scenario 2

	Glass area	ETFE area
Scenario 2 canopy minimal surface	688 m²	4031 m²
Scenario 2 canopy simulated	388 m²	4104 m²

Each of the four gable parts are open towards the main canopy, and have a ventilated opening at the top with an area of 3.2 m^2. The passages in the gables towards west is modelled as a room that is open towards the canopy.

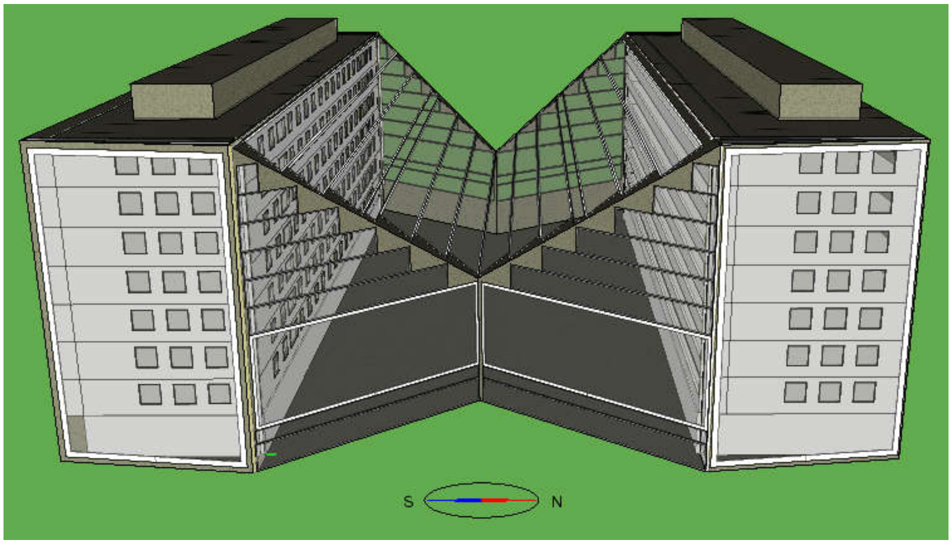


Figure 3.2.3 Scenario 2 IDA ICE model with canopy

The lowest 3 meters of the canopy gable are still 2-layer glass, and the rest of the canopy envelope is 4-layer ETFE. The gable walls of the apartment blocks and the windows in the gables are the original structures from before the renovation.

3.2.6. Simulation and result handling

Only energy simulation was performed. The simulation covers a period of one year. All results from the simulation were collected from the detailed simulation summary. Temperatures in the different zones and the canopy were investigated by the graphs that can be produced in IDA ICE. The energy data was collected from the Delivered energy report. The values were then exported to Excel for later use. Delivered energy for heating includes both space heating and domestic hot water production.

3.3. LCA methodology

3.3.1. Goal definition

The objectives of this study are to evaluate the environmental impact of alternative building renovation concepts that add a canopy between two existing buildings. The environmental impact of two different EKO-canopy scenarios will be compared with a traditionally renovation concept from the Swedish Million Homes Programme.

Another objective of this study is to investigate the impact of two future energy scenarios for the Swedish electricity and district heating grid. The energy grids will be assessed through dynamic LCA studies over a period of 50 years.

The target audience of this study is architects and engineers that work with renovation of buildings from the period 1960 – 1970. The dynamic LCA studies of the future energy grid is relevant for later scientific studies of the future impact from the energy consumptions.

3.3.2. Scope definition

The purpose of defining a functional unit is to make a definition where different products can be compared. The purpose in this project is a case study that compares the gained environmental impact from the construction of the EKO-canopy with the reduced impact from energy and renovation of facades facing the canopy.

The main function of the canopy in this study is to protect the facade, avoid a larger renovation of the facade, and reduce the energy loss from the building envelope. The canopy will also have several sub-functions as urban gardening and shared semi-outdoor space.

3.3.3. System model boundaries

The model should include all life cycle stages from raw material extraction to the disposal or reuse. Some of the processes in the life cycle stages can be very complex, and lack of information about the production can also be a limitation. These processes will normally be handled in the background system.

The foreground system will contain the final building products, the disposal of the products and the energy use for the building. The energy system is normally included in the background system. The dynamic energy simulations are modelled in the foreground system, but the production of the different energy sources like heat from heat pump or electricity production from nuclear plants and wind turbines or are placed in the background system. All life stages from raw materials to production are also located in the background system.

The different life cycle stages are identified and numbered in the standard DS EN 15978. The same identification is used in the DGNB certification approach and in most product EPD.

Table 3.3.1 Life cycle stages as defined in DS EN 15978

A 1 - 3			A 4 - 5		B 1 - 7							C 1 - 4				D
Product stage			**Construction process stage**		**Use stage**							**End of life stage**				**Benefits and loads beyond the system**
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Energy use	Water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling

Life cycle stages A1 – 3 will be included in the background of the system. The stages A4 – A5 and C1-C2 is subject to a lot of uncertainties. At the same time, the contribution from these stages is normally very small, so the stages from A4-5 and C1-2 are not included in the model.

In the use stage, only replacement and energy use are covered in foreground system of the model. The level of maintenance is generally low, so damaged building parts will normally be replaced.

The end of life stages C3 - C4 and the reuse, recovery and recycling stages will also be included in the modelled foreground system.

3.3.4. Data quality assessment

3.3.4.1. Input data

The areas and volumes of different materials are based on drawings from White architects and from Magnus Byberg, operating engineer at Väsbyhem. All drawings can be found in appendix C.

Most of the amounts for materials in the LCA must be inserted in kilograms. There is no data for the actual weight of the materials, so the weight of the materials is found by multiplying the volume of the different materials with the density of the respective materials. The density of the materials was found in tables in DS/EN ISO 10456 (Danish Standards, 2008).

3.3.4.2. Database

The database used for the LCA are Ecoinvent version 3.1. The database was released 8th July 2014, and is an addon to version 3 with new and updated datasets.

Several of the datasets from both the foreground and background system are updated in the new version (Moreno, Lévová, Bourgault, & Wernet, 2014). It is therefore important for the final results of the LCA that the Ecoinvent version 3.1 is used.

3.3.4.3. End of Life flows

It can be difficult to get data about the end of life stages of the product used in an LCA. Some of the information is kept secret by the companies, or is related to great uncertainties. The end of life stages can also vary a lot from country to country, even within Europe. Some countries have a large degree of recycling materials, while other countries have a large degree of landfill. These large differences can be related to both cultural and economic perspectives and are often a result of the waste handling policy in each country.

The Nordic countries generally have strict waste management policies with a large focus on waste sorting. The waste is either recycled into new products or incinerated and thereby converted to district heating and electric energy.

The end of life flows in this project are based on assumptions from other projects, SBi reports, and reports from the Danish Environmental Protection Agency. The assumptions are based on Danish waste management system, which can be assumed to be very close to the Swedish waste management system. Recycling rates of steel and aluminum is 90 % (Dall, Christensen, Hansen, & Christensen, 2003). There is no loss of materials in the end of life flows. All materials for municipal waste incineration will be converted to district heating.

3.3.5. System modelling

3.3.5.1. OpenLCA

OpenLCA is a free LCA software developed by GreenDelta in Germany. The software is open-source, which means that the source code to the software is available for everyone that wants to develop plug-ins or modify the program.

Commercial LCA software like SimaPro or GaBi costs a lot of money, making it difficult to use the software for smaller LCA studies due to the high price. The largest benefit of using OpenLCA is that the software is free, making it possible to make smaller LCA studies with reduced costs. OpenLCA offers some free databases, but more commercial databases such as GaBi and Ecoinvent databases can be purchased and then implemented in OpenLCA.

The software is easy to use, and has a clear interface. There are some limitations related to result handling, so the results from OpenLCA were exported from the software to Excel for further processing.

3.3.5.2. Flows

It can be an advantage in OpenLCA to subdivide the building system into smaller systems. The reason is that the end results will be shown for the total building system and not for the subcategories. Another problem is that it can take a lot of time to set up a dynamic scenario in OpenLCA. If some of the processes in a larger building system is changed, shall all dynamic scenarios be remade in OpenLCA.

Each building part flow was connected to a process with the same name. The process contained the materials use and the end of life flows.

The energy flow, like electricity and district heating, was created based on the different energy sources in the energy grid in Sweden. The total electricity use will then be divided between the different energy forms like nuclear power, wind or hydroelectric power. With this approach, is it possible to simulate how the energy mix will change in the future.

3.3.5.3. Dynamic scenarios and parameters

In OpenLCA is it possible to link the input data for the material flows with parameters. The parameters that were created were assigned with a name that referred to the material which the parameter is linked to. For example, a name for a parameter in the material flow for the north wall will be ``PRO_Stone_Mineral_Wool``, which means that the parameter is linked to the materials for production of stone mineral wool. Parameters that are linked to End of Life Flows will start with EoL, and avoided flows starts with AVO. In this way, it is easy to have an overview of the parameters when they are assigned to a scenario. The value for the parameters is 1 and the parameter is then inserted in the material amount under the process input and output tab.

OpenLCA offers the possibility to compare different scenarios. This has been used to make dynamic scenarios for each year of the building life cycle. Each year from 2020 to 2070 is created as a scenario. The scenarios are then named so that each scenario is one year of the period. This will be shown in the program like a matrix where the parameters for the chosen project system are the rows and the scenarios are the columns.

The inventory results can then be inserted into the matrix at the years where there is an action such as production, renovation, maintenance or demolition. The material amount for production is inserted as positive. Material amounts for end of life flows and the next system avoided products are inserted in the matrix as negative values.

3.3.5.4. Energy scenarios

The dynamic energy scenarios are based on a report from the Swedish Energy Agency, which tries to predict four possible energy scenarios for the Swedish future energy grid (Swedish Energy Agency, 2016). The background data for the report can be found on the webpage for the Swedish Energy Agency (Energimyndigheten, 2017). The Excel document on the webpage shows the energy production for both electricity and district heating for a 2014 reference year, and then the predicted energy production for the four scenarios in 2035 and 2050. The energy scenarios can be found in appendix D.

The dynamic scenarios in OpenLCA is based on the percentage of energy production from difference sources, so the production data in the Excel document was recalculated from TWh to percentage of the total production. The development of the share of the different energy sources follows a linear trend with 2014, 2035 and 2050 as references. It is assumed that the energy system will stop developing after year 2050. All wind energy in the scenarios is assumed to be onshore. Biofuels is represented as biomass in the model.

3.3.6. Impact assessment method

The methodology use for impact assessment is the ReCiPe 2008. The ReCiPe methodology consists of eighteen midpoint indicators scores and three endpoint indicator scores. It can be difficult to cover all eighteen midpoint indicators in the results section, due to the limited length of the report. Five midpoint indicators have been chosen to represent the results for the midpoints. The five indicators are climate change (CC), ozone depletion (OD), terrestrial acidification (TA), freshwater eutrophication (FE) and photochemical oxidant formation (POF).

The normalization set for the impact categories are the cultural perspective called Europe ReCiPe Hierarchist (H). The timeframe for Hierarchist is 100 years, which fits well for building applications.

There are two other cultural perspectives, which are called the Egalitarian (E) and the Individualist (I). The Egalitarian covers a timeframe of 500 year, which is rather too long when the timeframe of the building is 50 years. The individualist is only covering a timeframe of 20 years and does not include a characterization factor for CO_2 (Goedkoop, 2013).

3.3.7. Results handling in Excel

Impact results are exported from OpenLCA as notepad files. The files can then be imported to Excel as datafiles. It is not possible to investigate all processes in OpenLCA, so the model is divided into several sub-models in OpenLCA. These sub-models will be combined in Excel to one single model. Every sub-model includes several process models. The process models are parts of the OpenLCA model where the data for the impact assessment is removed. A process model could be the windows in the north facade, or steel in the canopy.

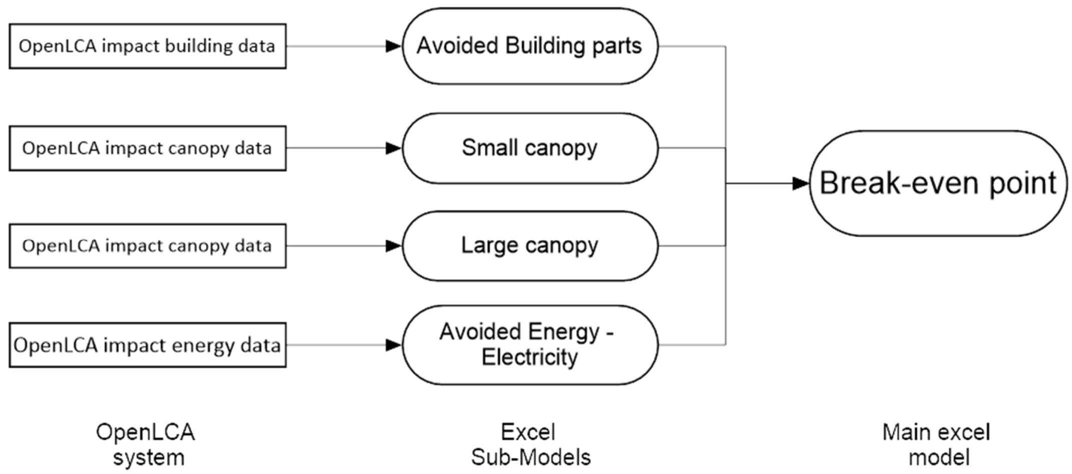


Figure 3.3.1 Excel model system

In total, there will be 4 Excel sub-models that are linked to one main Excel model. The main Excel model will be used to find the Break-even point for the different scenarios. Because the sub-models and the main model are linked together, it is important that the Excel files are kept in the same folder location at all time.

3.3.8. Sensitivity of model

One of the main purposes is to investigate the reliability of the results from the study. A sensitivity analysis is required if the study is intended to be disclosed to the public (Danish Standards, 2008). The sensitivity analysis can be performed doing different steps in the LCA study. For example, a more general assessment of the sensitivity can be performed during the scope of the project. The early phase sensitivity will be an assessment of the available or needed data, to secure a proper data foundation. If it is assessed that the sensitivity for a certain part of the system is low, the data collection for that part of the system can have lower priority. These early phase sensitivity analyses are general assessments and not based on calculations, and can therefore be affected by uncertainties (European Commission Joint Research Centre, 2010).

The sensitivity analysis in the project is conducted after the impact assessment and are based on the sensitivity ratio that can be calculated after equation 3.3.1.

$$SR = \frac{\frac{Y_2 - Y_1}{Y_2}}{\frac{X_2 - X_1}{X_2}}$$

Equation 3.3.1

Where: SR is the sensitivity ratio

Y_1 is the impact output before changing the input

Y_2 is the impact output after changing the input

X_1 is the base parameter input to model

X_2 is the changed parameter input to model

The sensitivity analysis in this study calculated the sensitivity ratio after the input parameters from the inventory are increased by 10 %. When all the parameters in OpenLCA were updated, the impact assessment was recalculated. The result was then exported to Excel so the sensitivity ratio could be calculated. Building and canopy parts were already divided into several shared processes in OpenLCA. Some of the shared processes, such as windows or canopy glazing, included several Ecoinvent database processes. The materials in the shared processes are linked together because it is glazing and frame, so both materials were increased with 10 % at the same time. The sensitivity ratio is therefore calculated on sub-process level, and not single database process level. Because all sub processes are increased with 10 %, fixed values are used for X_1 and X_2.

The sensitivity ratio of the processes for energy sources in the dynamic energy scenarios cannot be calculated. The reason for this is that, when aggregated, the percentage of the energy sources will give 100 %. If the processes for the energy sources are increased with 10 %, the value will be above 100 %, which means that other energy sources will then have to be decreased. The result will not represent the result of a dynamic energy scenario, because the model will be changed to another scenario. The dynamic electricity scenarios were instead investigated by increasing the annual energy consumption with 10 %. The sensitivity ratio is calculated in relation to the final aggregated impact for all five impact categories used in the impact assessment.

4. Results

4.1. Life Cycle Inventory and energy use

This chapter will present the results of the IDA ICE energy simulations and the inventory analysis.

4.1.1. Canopy indoor temperature

Heat loss from the apartments is dependent on the outdoor temperature. The behavior of the indoor climate within the canopy will therefore have an impact on the heat loss from the apartments. Some of the natural ventilation through the facade will also come from the canopy. If the air from the canopy is preheated, it will also result in a smaller heat loss for the apartment. The canopy should not be too warm in the summer or too cold in the winter. The canopy is heated and cooled only by passive systems. There is no heat unit in the canopy, so it can only be heated by the heat loss from apartments, and the solar radiation through the transparent surface area. The cooling will come from natural ventilation of the canopy though the roofs and gables. Internal mass in the ground, in water ponds and water tanks within the canopy will help to stabilize the indoor temperature.

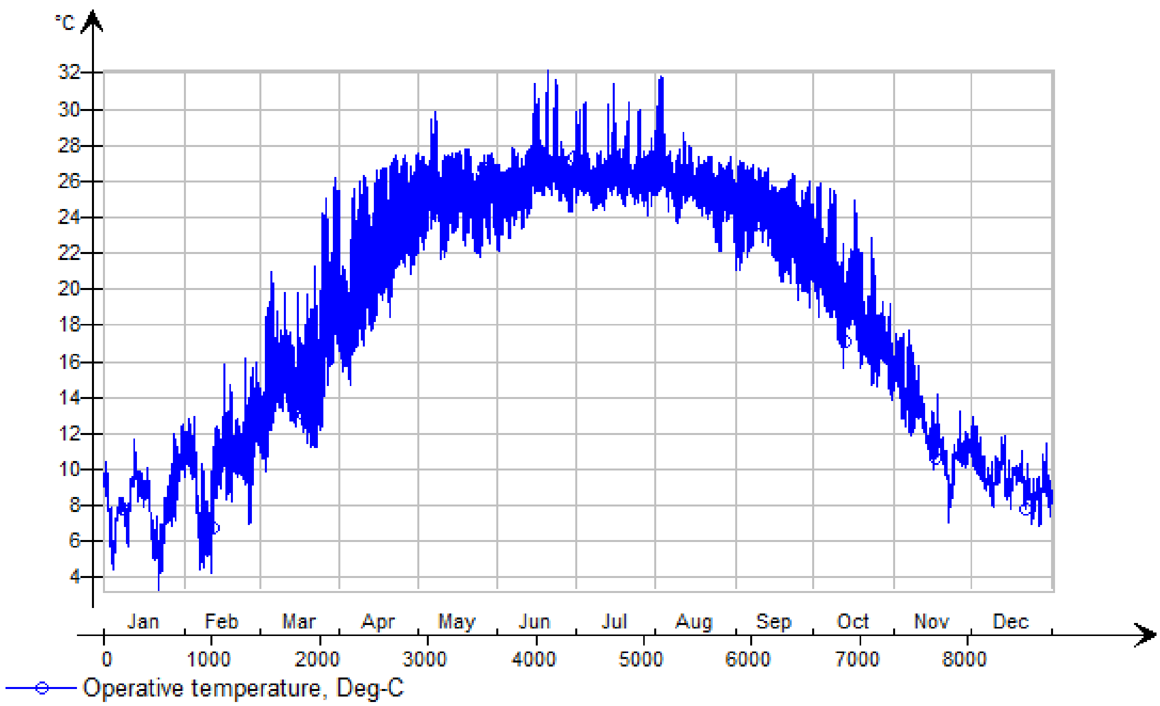
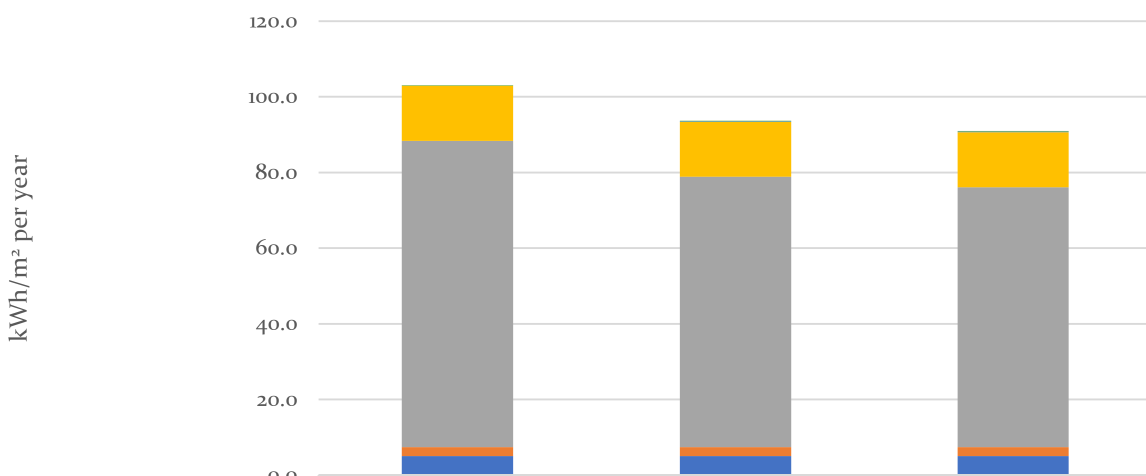


Figure 4.1.1 Canopy annual indoor temperature

The results of the simulated canopy indoor operative temperature in figure 4.1.1 shows that it is possible to obtain an acceptable indoor temperature in the canopy during the year. It is important to mention that the canopy cannot be compared with a normal heated living area. The canopy should be investigated as a semi-outdoor space that can help extend the outdoor period of the year. The results show that the temperature will be above freezing at all times. Another important point is that the canopy can be cooled only with natural ventilation. The temperature in the summer will there be in the range of 25 °C to 30 °C most of the time. If further cooling is need, some of the roof of the canopy can be covered with non-transparent ETFE or photovoltaic cells.

4.1.2. Delivered energy

The two apartment blocks have a total heated floor area of 12290 m². Figure 4.1.2 shows that the total energy consumption for both canopy scenarios is lower than the reference renovation concept. The delivered energy is without primary energy factors, because the energy will be used in dynamic LCA simulations. The second canopy scenario with the canopy that also covers the gables will result in a reduction of the heating load compared to the scenario 1 canopy. The energy consumption of the Thermia Vent unit for the heat pump and the ventilation system are the same in all simulated cases. The district heating is mainly used for heating of domestic hot water. There is a very small difference in energy consumption between the cases for district heating and lighting.



	Renovated	Scenario 1	Scenario 2
Thermia Vent	0.2	0.2	0.2
Blowing stations energy use	0.0	0.1	0.2
District heating	14.5	14.5	14.5
Heat pump	81.1	71.5	68.7
Ventilation	2.4	2.4	2.4
Lighting	5.0	5.0	5.0

Figure 4.1.2 Annual delivered energy

The blowing stations that maintain the air pressure in the ETFE cushions and the energy use for the Thermia Vent unit are not simulated in IDA ICE, but based on product descriptions and environmental product declarations. The difference in annual energy consumption related to district heating is around 128 kWh per year, which is very small compared to the aggregated annual consumption.

4.1.3. Canopy materials

The area of the two canopy proposals are determined by a minimal surface. Most of the canopy will be an ETFE construction, but the lower 3 meters above the ground will be 2-layer glazing. The canopy in scenario 1 will have an ETFE area of 2896.0 m^2 and a glazing area of 312.7 m^2. The canopy in scenario 2 also covers the gables, so the areas will therefore be increased. In this case, the ETFE area will be 4031.4 m^2 and the glazing area will be 687.9 m^2. All detailed inventories for the two canopies can be found in appendix E. The end of life flows for the different materials can be found in appendix F.

The structural properties of the canopy with a minimal surface have not been calculated. Structural calculation is beyond the scope of this project, so the structural parts are based on reference projects. The structural system of the glazing areas of the canopy is based on the reference project Academy Mont Cenis Herne. The large glass construction in Mont Cenis is made with 2-layer glazing. The construction has 0.1 m^3 of structural timber per m^2 glass surface. In addition, there is 9.7 kg of structural steel per m^2 glass surface. These amount-to-area references are multiplied with the glass areas of the canopies to determine the amount of Structural timber and steel in the two canopy proposals. 95 % of the glazing area consists of 2-layer glazing. The last 5 % of the glazing area is the aluminum glazing frame.

Table 4.1.1 Materials for scenario 1 canopy

	Lifetime	End of life flow	Weight [kg]	Area [m^2]	Volume [m^3]	Items
ETFE	25	11	2595			
Aluminum profiles	60	7	11642			
Silicone sealing	25	12	614			
Glass	25	6	5941	297		
Aluminum window frame	25	7	985	16		
Structural timber	120	5	9517		21	
Steel	60	2	3021			
Glued timber beam	120	5	6480		14	
Total			40795			
Pump	25	2				5

The main materials for the ETFE part of the canopy is silicone sealing, aluminum profiles and ETFE. The ETFE materials covers both the film for the cushion and the air supply pipes that are placed within the aluminum profiles. The material amounts for the ETFE surface is based on a EPD of a Texlon ETFE system developed by Vector Foiltec (Institut Bauen und Umwelt e.V., 2014). The different amounts of materials in the system is 0.896 kg ETFE per m², 4.02 kg aluminum per m² and 0.212 kg silicone sealing per m². One pump of 60 W can maintain the pressure in a system of 1000 m² ETFE cushion system. The pump in the model is a 40 W pump, so 5 pumps are needed in the scenario 1 canopy and 7 pumps are needed in the scenario 2 canopy based on the ETFE area.

Table 4.1.2 Materials for scenario 2 canopy

	Lifetime	End of life flow	Weight [kg]	Area [m²]	Volume [m³]	Items
ETFE	25	11	3612			
Aluminum profiles	60	7	16206			
Silicone sealing	25	12	855			
2-Layer glazing	25	6	13070	653		
Aluminum window frame	25	7	2167	34		
Structural timber	120	5	20936		47	
Steel	60	2	6646			
Glued timber beam	120	5	6480		14	
Total			69972			
Pump	25	2				7

A curved, glued timber beam is placed in the middle of the canopy to stabilize the ETFE system. The glued timber beam is connected to the glass gables with a span of 72 meters. The cross section of the beam is 0.2 m².

4.1.4. Avoided building materials and energy

The avoided building materials cover all facades that are facing the canopy. The avoided materials include the difference in materials between a nonrenovated facade and a renovated facade. It is assumed that the surface of the building facades facing the canopy also will be rendered, due to the bad condition of the aluminum plates.

All material amounts for the renovations are based on drawings and product descriptions from Sto Scandinavia AB.

The north wall in the block is a light wooden construction with stone wool insulation and outer metal cladding. There is a wind plate between the wall and the ventilated cap behind the metal cladding. This wind plate is made of asbestos cellulose which is categorized as a dangerous material when it is damaged and gets airborne. The small asbestos fibers can then get stuck in the lungs and raise the risk of getting lung cancer. Handling asbestos materials can be very expensive and time-consuming due to the high level of safety required. The north wall was therefore renovated without removing the asbestos cellulose boards. The renovation system used for the north facade is called StoVentec Facade System. The system contains a thin aluminum frame that is attached to the wall, which in this case is the asbestos cellulose boards. The space between the frames is then insulated with Sto Cotex One stone wool batts. The surface of the construction is a high-density glass fiber board attached to the frame with render on the outside.

Table 4.1.3 Amounts of avoided building materials for facades

	Material	Lifetime	Thickness [mm]	Area [m^2]	Amount [m^3]	Density [kg/m^3]	Weight [kg]	EoL Flow
Facade ground level north	XPS insulation board	80	80	173.4	13.9	65	902	1
	mortar	120	5		0.9	1900	1647	4
	Granite tiles	120	15		2.6	2600	6763	8
Facade ground level gables	XPS insulation board	80	80	55.7	4.5	65	290	1
	mortar	120	5		0.3	1900	529	4
	Granite tiles	120	15		0.8	2600	2172	8
Facade ground level south	XPS insulation board	80	80	115.6	9.2	65	601	1
	mortar	120	5		0.6	1900	1098	4
	Granite tiles	120	15		1.7	2600	4508	8
Facade north	Stone mineral wool	80	70	1108.6	77.6	80	6208	10
	Aluminum profiles	80	1		0.1	2800	310	7
Facade gables	EPS insulation board	80	100	359.5	36.0	50	1798	1
Balcony at south facade	laminated glass	40	8.76	600	5.3	2500	13140	9
Windows north	3-layer window glazing	25	-	281.5	-	-	8444	6
	Aluminum window frame			31.3	-	-	1970	7
Windows west and east	3-layer window glazing	25	-	79.0	-	-	2369	6
	Aluminum window frame			8.8	-	-	553	7
Windows south	3-layer window glazing	40	-	556.4	-	-	16691	6
	Aluminum window frame			61.8	-	-	3895	7

All windows areas are assumed to be 90 % glazing and 10 % aluminum frame. The metal cladding on the external balconies is removed and replaced with colored laminated glass with a thickness of 8.76 mm.

The original gables of the blocks consist of 150 mm concrete wall with 50 mm solid insulation and blue metal cladding on the outside. The metal cladding and the old solid insulation boards were removed during the renovation and replaced with a new ESP insulation board of 100 mm. The surface of the solid insulation board was then covered with a 2 mm thick layer of mortar, followed by a 2 mm layer of colored facade render.

Before the renovation, all ground walls were 150 mm concrete walls with 5 mm mortar and 15 mm yellow glazed tiles as outer surface. Tiles and mortar were removed during the renovation and replaced with new 80 mm XPS insulation boards with 4 mm new mortar and new grey granite tiles as outer surface.

4.1.4.1. Avoided energy

The energy input to the LCA model will only be the differences in energy consumption related to district heating and electricity. Figure 4.1.3 shows the annual avoided energy for the two canopy renovation concepts related to the reference traditional renovation. The results from the energy simulation showed that the annual avoided electricity consumption would be 22 % higher for the scenario 2 canopy renovation compared to the scenario 1 canopy renovation. The saved electricity is mainly related to space heating from the heat pump.

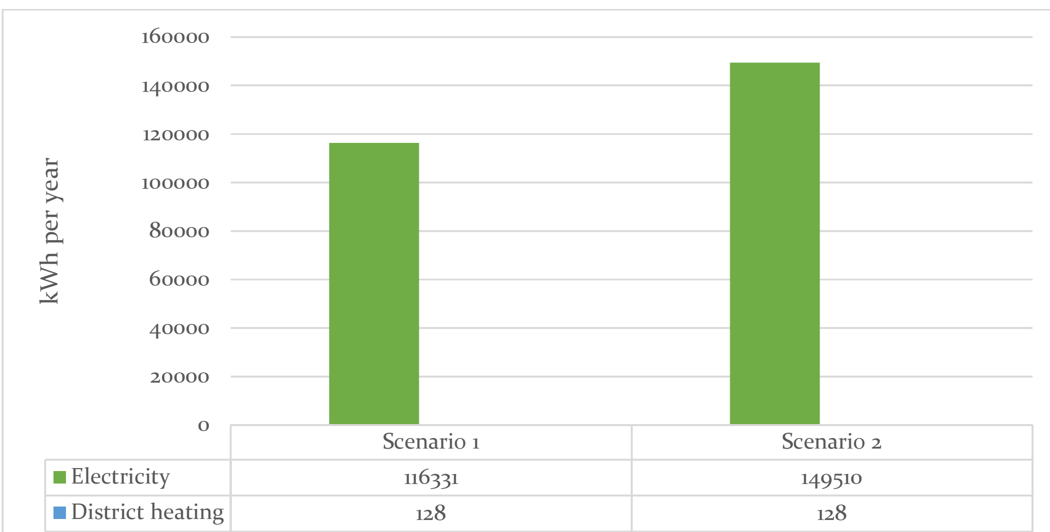


Figure 4.1.3 Annual avoided energy consumption

The annual avoided energy consumption from district heating is very low compared to the avoided electricity. Because the annual avoided district heating consumption is so low, it is not included in the LCA model.

4.2. Impact assessment

The impact assessment results are divided into two groups: Impacts and avoided impacts. These two groups will then be used to find the break-even point, and the aggregated total avoided impacts over 50 years. Impacts will come from the materials for the canopy. The avoided impacts will come from avoided renovation materials and saved energy consumption in the use phase. The results will be presented related to the four future dynamic energy scenarios and a standard nondynamic energy scenario.

Some of the material processes have waste incineration as a part of the materials' end of life. This waste incineration will be used for district heating, which means that there will be an avoided product, which is district heating in the end of life of the material. These avoided products can have a large effect on the impact results. Figure 4.2.1 shows the climate change impact for the four future dynamic energy scenarios and a standard nondynamic energy scenario per kWh.

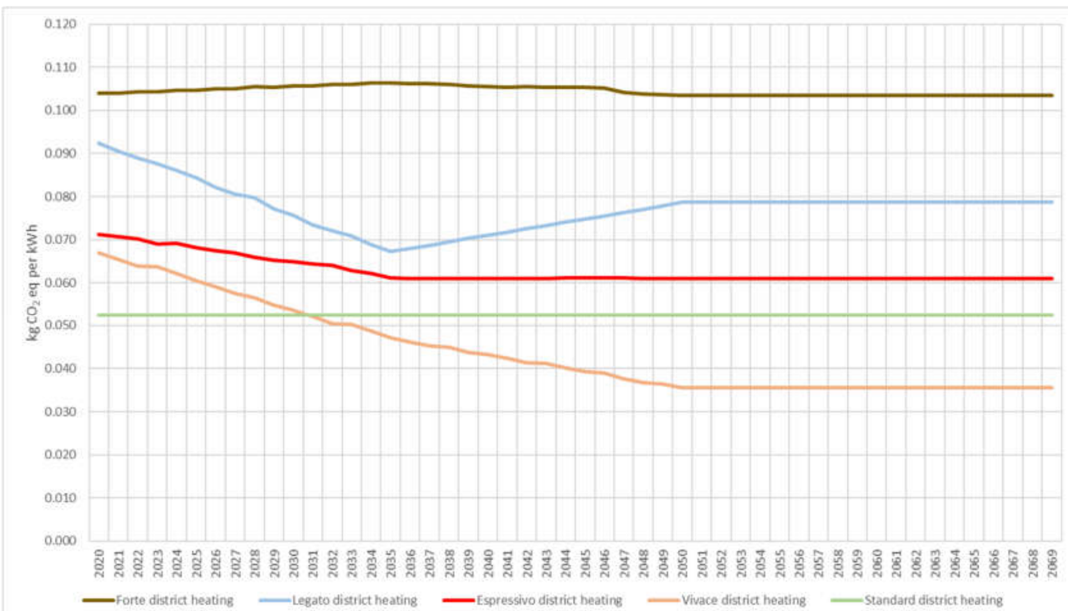


Figure 4.2.1 Climate Change impact from district heating per kWh

The results show that the choose choice of energy scenario will have a large influence on the climate change impact from avoided products. For example, will the climate change impact in 2069 for the Forte scenario be 2.9 times larger than in the Vivace scenario.

Some of the scenarios have a large climate change impact variation over the period of 50 years. This can also be important to consider when choosing the year for material incineration in the end of life phase of the LCA. For example, the next product climate change impact from district heating in the Legato scenario will be almost 10 % larger in 2050 compared to the impact in 2040.

Some of the material flows in the impact assessment do not contain material incineration and will only be presented as a standard scenario. Material flows with dynamic aspects will be presented as 5 scenarios.

4.2.1. Impacts from canopy materials

4.2.1.1. Climate change potential

The impact results are divided into canopy component categories. This makes it possible to investigate the impact of the various canopy components and see the contribution from different materials. The results presented in this chapter are from the impact of the scenario 2 canopy, which is the largest canopy of the two scenarios. Results for the canopy in scenario 1 can be found in appendix G.

The category called ETFE includes both the ETFE film and pipes. Datasets for ETFE foil was not available in the database, so polyvinyl fluoride film is used instead. Polyvinyl fluoride film has some of the same properties as ETFE foil, and is often used as a protection film for objects that are exposed to outdoor conditions (Ebnesajjad, 2012).

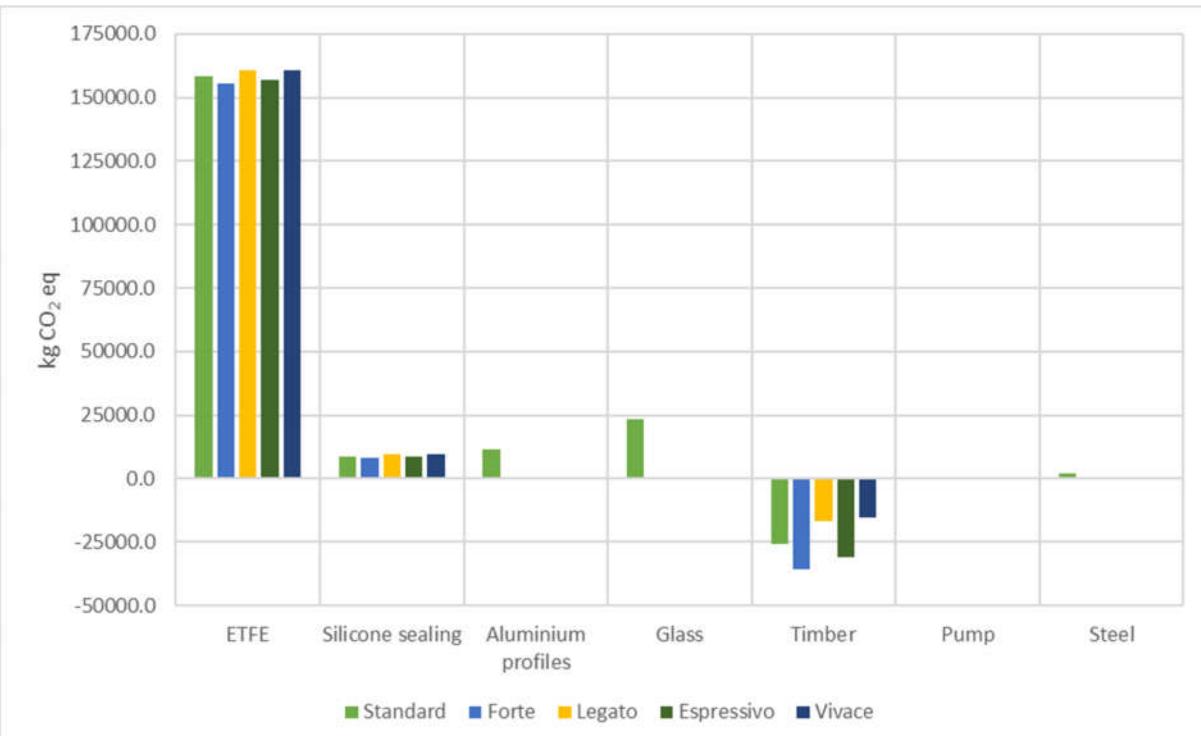


Figure 4.2.2 Canopy scenario 2 Climate Change

Figure 4.2.2 shows the aggregated climate change potential impact over the canopy's lifetime of 50 years. The results show that the ETFE are responsible for the highest impact. Both the real ETFE film and the polyvinyl fluoride film that are used has a high flammable resistance. The results show that the impact from the incineration of the polymer film is very large. It is possible that the high climate change impact in material incineration of the ETFE can be related to the polymer films high flammable resistance.

The aggregated climate change impact from timber includes both structural timber and the large glued timber beam. The impact from timber will be negative because timber acts like bio mass when it is incinerated for producing district heating or electricity. The timber in this model has district heating as a next stage avoided product. The results show that the different future energy scenarios have a high influence on the aggregated impacts for timber. The difference between some of the scenarios are more than a factor of 2.

4.2.1.2. Ozone depletion

The structural timber and the glued timber beam in the canopy have the largest impact related to ozone depletion potential as shown in figure 4.2.3. The impact is negative, which means that there will be an avoided impact. The detailed dynamic plots that can be found in appendix H, shows that the negative impact happens in the end of life stage.

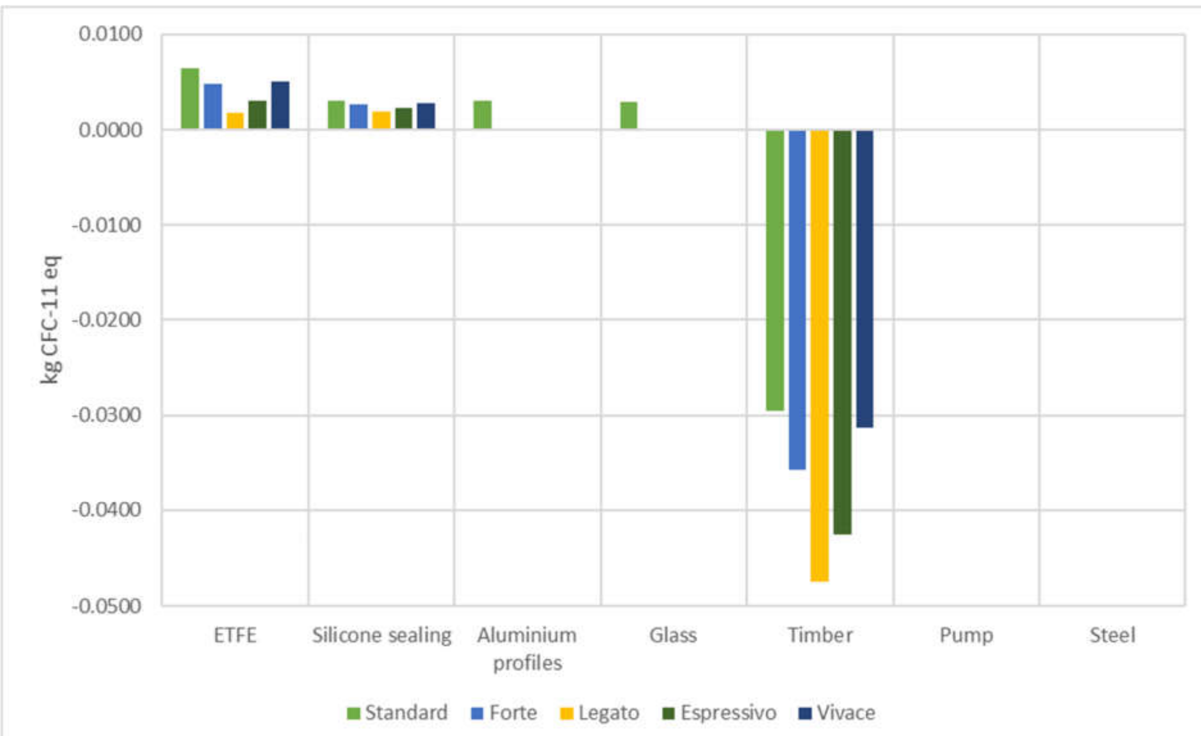


Figure 4.2.3 Canopy scenario 2 Ozone Depletion

The impact in the production stages of timber are relatively small. The negative impact is most likely related to the incineration of waste wood for district heating production. The results show that the future energy scenarios for district heating has a high influence on the amount of avoided kg CFC-11 (trichlorofluoromethane) equivalents. The total impact for the large canopy will be negative for all five scenarios. Legato will have the highest negative of -

0.0376 kg CFC-11 equivalents. A European person equivalent in relation to ozone depletion potential is 0.022 kg CFC-11 equivalents, according to the ReCiPe Hierarchist. This means that that the total avoided impact in the Legato scenario will be the same as 1.7 European person equivalents in relation to ozone depletion potential. The standard scenario will have the lowest avoided impact of the 5 scenarios, which is 0.63 European person equivalents.

4.2.1.3. Photochemical oxidant formation

The ETFE materials has the highest impact of all canopy materials related to photochemical oxidant formation. The impact unit of POF is kg NMVOC (Non-methane volatile organic compound) which represents a range of different Non-methane hydrocarbons. These Non-methane hydrocarbons are normally used in the production of crude oil. The Polyvinyl fluoride material that is used instead of ETFE is a material that is based on oil products. Some of the main compounds in the polyvinyl fluoride film are Non-methane hydrocarbons. Most of the impact from Polyvinyl fluoride film happens in the production phase. Some of these non-methane hydrocarbons are emitted when the polyvinyl fluoride film is burned in the end of life, which also gives a large impact in the end of life from the incineration. The avoided impacts from district heating are still a little bit larger, so the impacts in the end of life stages will still be negative. ETFE film is based on some other non-methane hydrocarbons. So it cannot be confirmed that ETFE and Polyvinyl fluoride film will have the same impact related to photochemical oxidation formation.

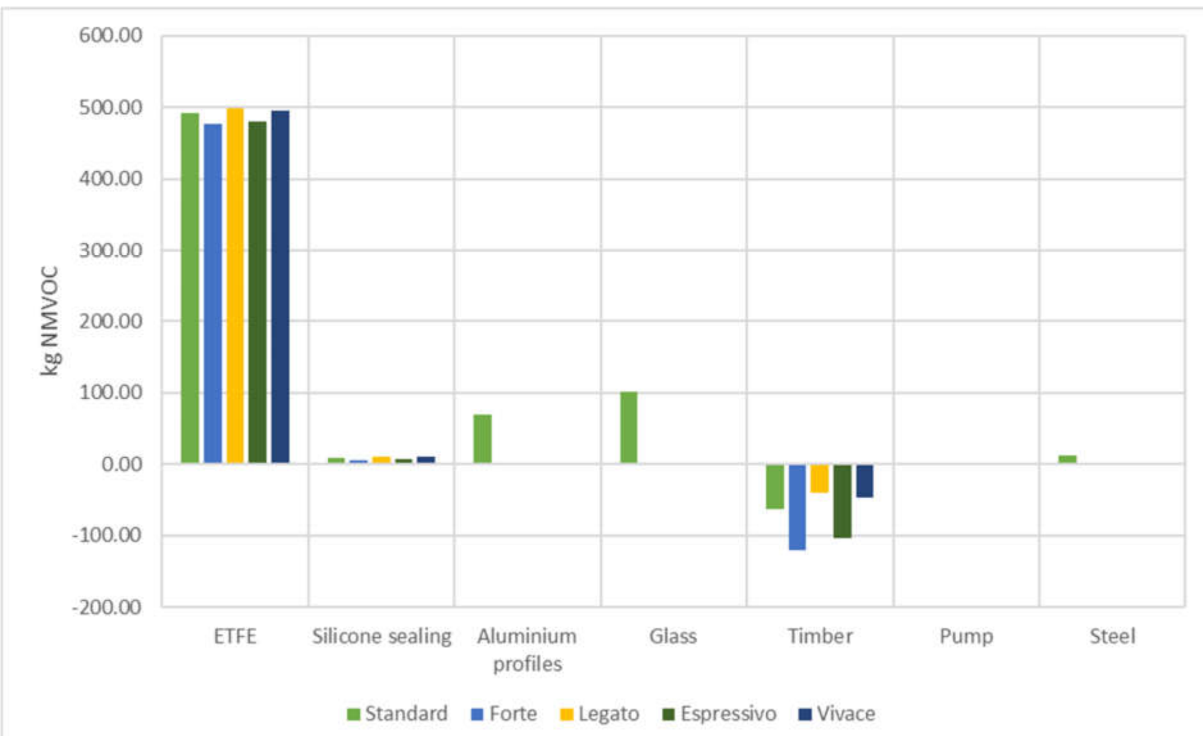


Figure 4.2.4 Canopy scenario 2 Photochemical Oxidant Formation

The aluminum profiles have the highest impact in the production stages. Aluminum has a high recovery rate with a high efficiency of the recovery process, which means that the negative impact from avoided products in the end of life compensates, so that the total impact of all stages in the aluminum profiles are generally low compared to ETFE and Glass. The timber materials will again contribute with a negative impact, because the timber is incinerated for district heating production. Again, it can be seen that the dynamic scenarios have a high influence on the total impact of the timber scenarios. The dynamic influence of the ETFE materials are much smaller. The reason for this is that most of the impacts happened in the production phase, which is not dynamic like the end of life phases.

Again, the Legato scenario have the highest impact, which will be the same as 11.5 European person equivalents. The Forte scenarios have the lowest impact which is 9.6 European person equivalents.

4.2.1.4. Terrestrial acidification

The terrestrial acidification (TA) covers the deposition of inorganic substances related to SO_2, NO_x and NH_3. The unit for TA is kg SO_2 equivalents, where NOx substances contributes with a factor of 0.56, while NH_3 substances contributes with a factor of 2.45 (Goedkoop, 2013).

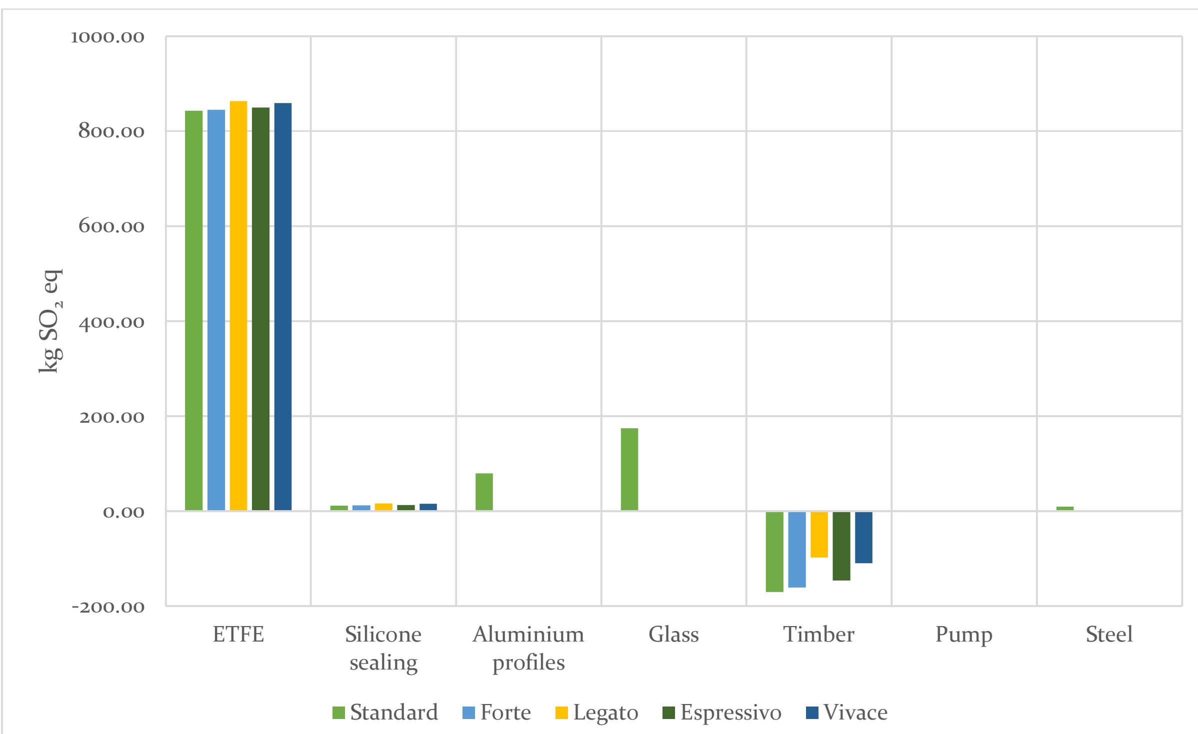


Figure 4.2.5 Canopy scenario 2 Terrestrial Acidification

The distribution of TA impacts in the different materials categories are similar to the distribution of the impacts related to photochemical oxidation formation. One of the largest differences is that the dynamic scenarios behave differently related to TA. The standard scenario is now the scenario with the lowest impact. The results in figure 4.2.5 shows that the standard scenarios has the highest avoided impact related to timber by the lowest impact related to the ETFE. The scenario with the highest impact is again the Legato scenario which results in a total of 30.4 European person equivalents, while the standard scenario has 27.6 European person equivalents.

4.2.1.5. Freshwater eutrophication

The substances included in freshwater eutrophication are phosphorus (P) and nitrogen (N), where phosphorus is used as the reference unit. The emissions in freshwater eutrophication will normally emerge from sewage treatment plants or fertilizer and manure used in agriculture (Goedkoop, 2013).

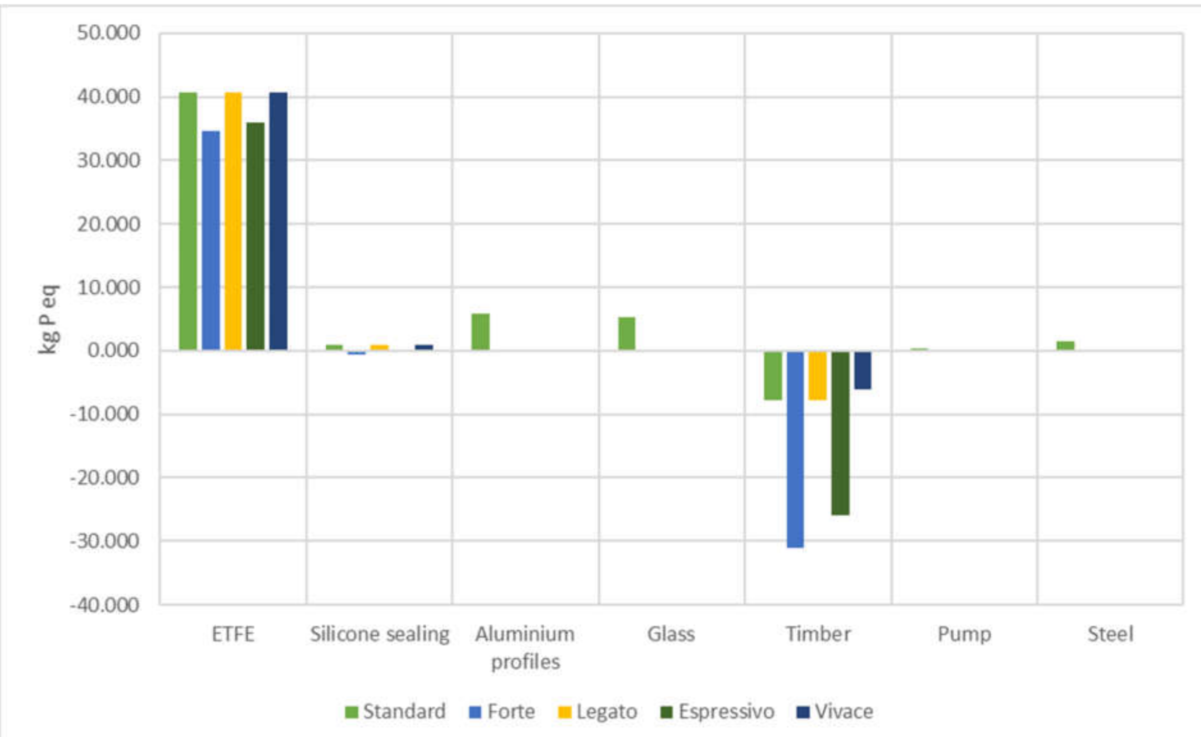


Figure 4.2.6 Canopy scenario 2 Freshwater Eutrophication

The impacts in figure 4.2.6 shows that the scenario has a large influence on the aggregated impacts. This large deviation between the scenarios indicates that the impact occurs in the district heating system. While the impacts between the scenarios are different from the other impact categories, the pattern in impact between the different materials flows is very similar to the other impact categories.

Legato is still the scenario with the highest aggregated impact of 11 European person equivalents while Forte has the lowest aggregated impact with 4.25 European person equivalents.

4.2.2. Avoided renovation materials

4.2.2.1. Climate change

Windows are the most dominating building part in relation to climate change impacts as shown in figure 4.2.7. The south facade has the largest window area, which also the reason the impact from south orientated windows is larger than for the north facade and the gables. Windows include both the glazing and an aluminum window frame. The detailed graph for climate change for avoided building materials in appendix I shows that the impacts from windows changes through the year. Windows are installed in the year 2020, replaced in 2045 and removed in 2070. In 2020, the only impact from windows are related to the productions of both glazing and the aluminum frame. In 2045 there will be impacts from both production and disposal of old windows and frames. There will also be some avoided products related to the aluminum in 2045, which is the reason the impact in 2045 is lower than in 2020. In 2070, there will only be a negative impact from windows due to the next system's avoided aluminum.

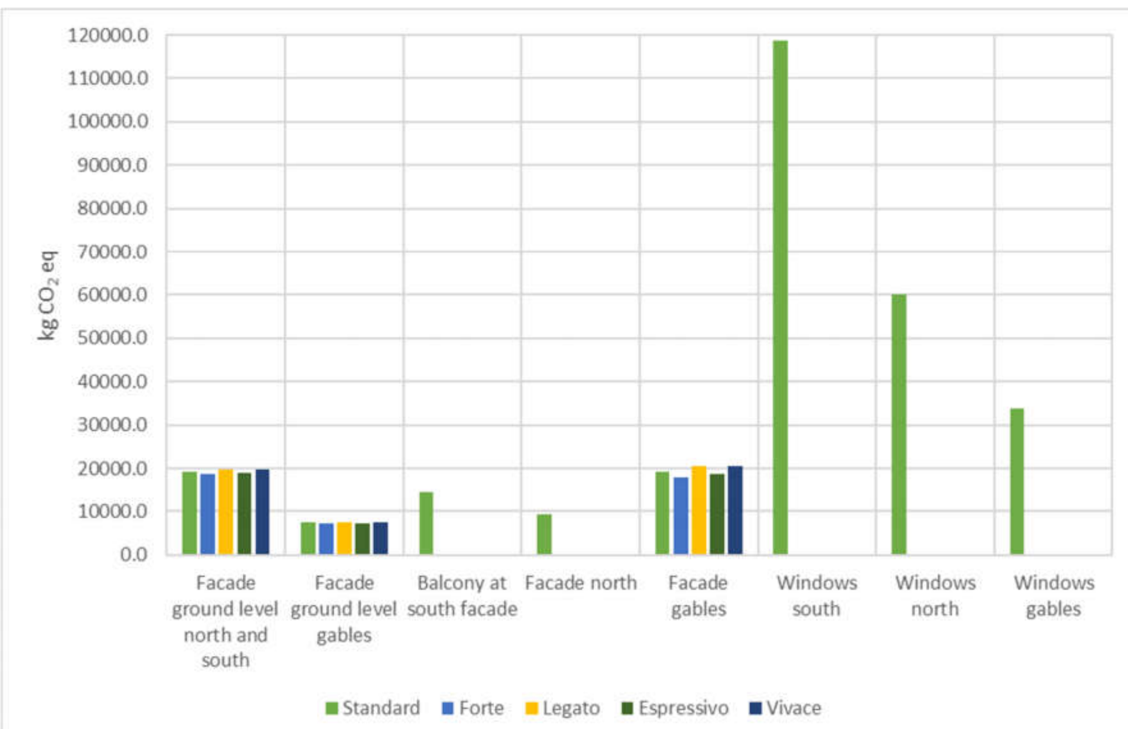


Figure 4.2.7 Avoided renovation materials Climate Change

The climate change impacts between the energy scenarios in the different building part categories are very small. Because the windows are the dominating part, the final aggregated impact between all five scenarios will also be very small. The Vivace scenario will have the highest impact that results in 25.3 European person equivalents over the period of 50 years. The Forte scenario will have the lowest impact with equal to 25 European person equivalents of CO_2.

4.2.2.2. Ozone depletion

The impact results from ozone depletion in figure 4.2.8 shows that most of the impacts are negative. One common characteristic between the building part categories is that they have district heating as a next system avoided product. The negative impact from the gable facades are very large compared to the other building part categories, which is most likely due to the high degree of incinerated expanded polystyrene that is converted to district heating. The window categories will also give a negative impact, but there will also both be an avoided impact from the aluminum and some incineration of silicone sealing that is converted to district heating. This happens inside a standard Ecoinvent data process which is the reason the process is not dynamic.

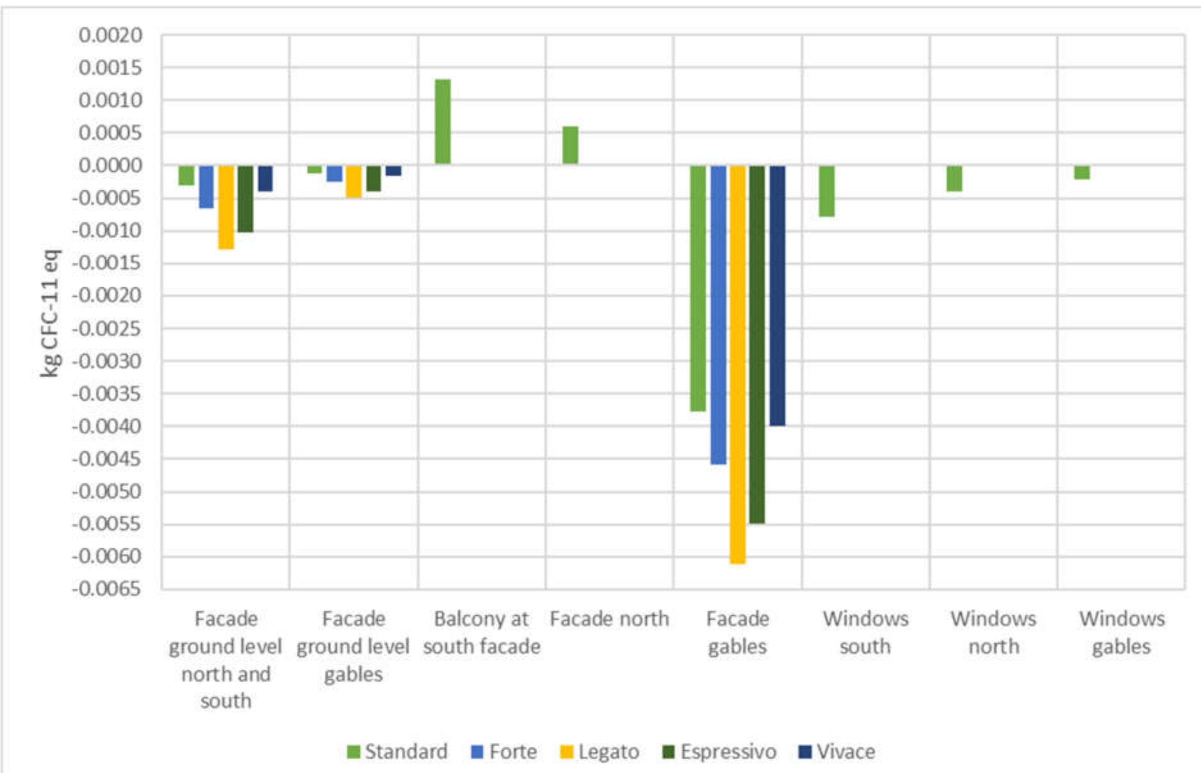


Figure 4.2.8 Avoided renovation materials Ozone Depletion

The future energy scenarios have a large influence on the aggregated impact, which also strongly indicates that the negative impact is related to the avoided district heating. For example, the negative impact of the Legato scenario is two time higher than the standard non-dynamic scenario. The aggregated impact of the Forte scenario will be equal to -0.34 European person equivalents and the standard scenario will result in -0.17 European person equivalents in relation to ozone depletion over the 50 year period.

4.2.2.3. Photochemical oxidant formation

The impact from photochemical oxidant formation shows a very similar distribution between the building parts, as in the climate change impacts. Again, the windows are the most dominating category of all building parts. According to the detailed graphs for photochemical oxidant formation for avoided building parts that can be found in appendix I, the aluminum is responsible for around 30 % of the impacts for the windows. The rest of the impact for the windows are related to the glazing.

Impacts from ground facades and the gables are not positive. All facades except the north facade contains polystyrene, which is an polymer material that consists of hydrocarbons $(C_8H_8)_n$. It is likely based on the results that the polystyrene is responsible for most of the impacts for the facades. The impacts emerge in the production phase, which is very clean in the gable facade where only polystyrene is included.

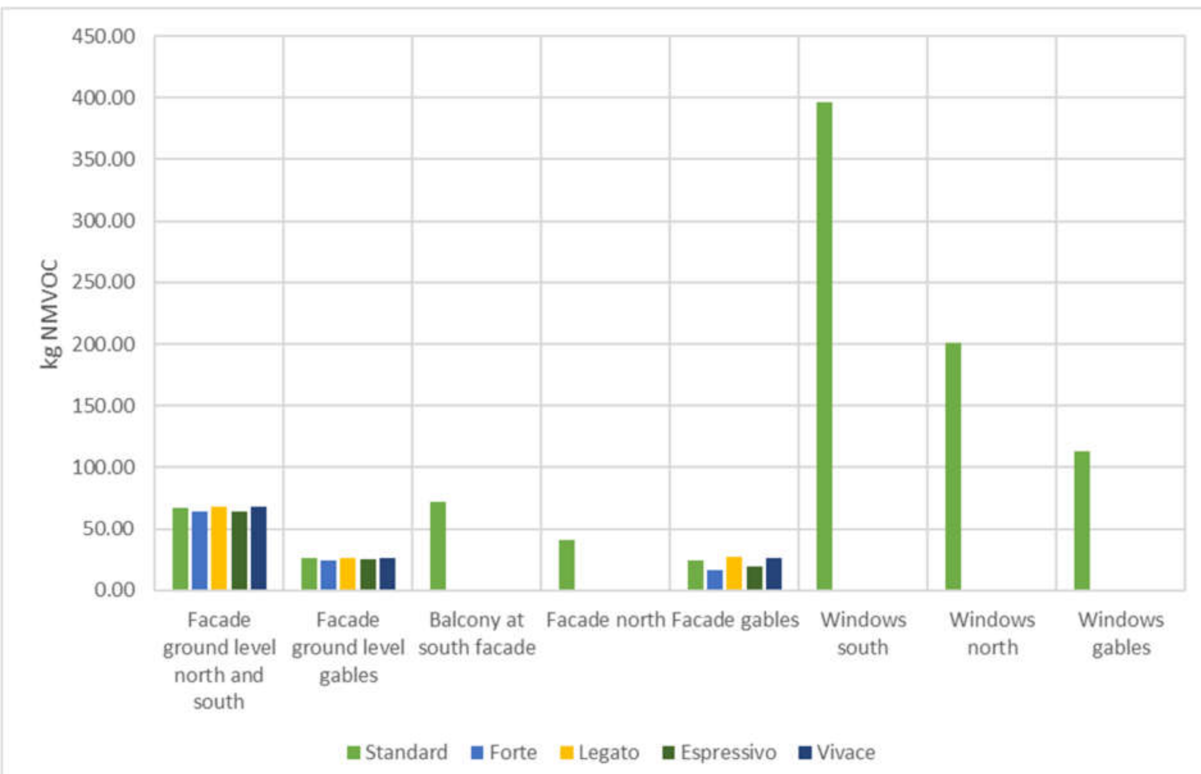


Figure 4.2.9 Avoided renovation materials Photochemical Oxidant Formation

The negative impact from avoided district heating are small, which is the reason the difference between the scenarios is also small, as shown in figure 4.2.9. The Legato scenario will have the highest impact resulting in 16.6 European person equivalents while the Forte scenario will result in 16.3 European person equivalents in relation to Photochemical oxidant formation over the 50-year period.

4.2.2.4. Terrestrial acidification

The terrestrial acidification impact from windows is very high compared to the facade materials as shown in figure 4.2.10. SO_2 is normally released in larger amounts when burning fossil fuels, especially from coal. Both aluminum and glass consume a lot of energy in the production due to the required high production temperatures. The detailed graphs in appendix I show that most of the impacts occur in the production stages while the end of life stages gives a negative impact due to the avoided aluminum from the frames. The negative impact is only around a 25 % of the positive impact, which is the reason for the high final aggregated impacts from the windows.

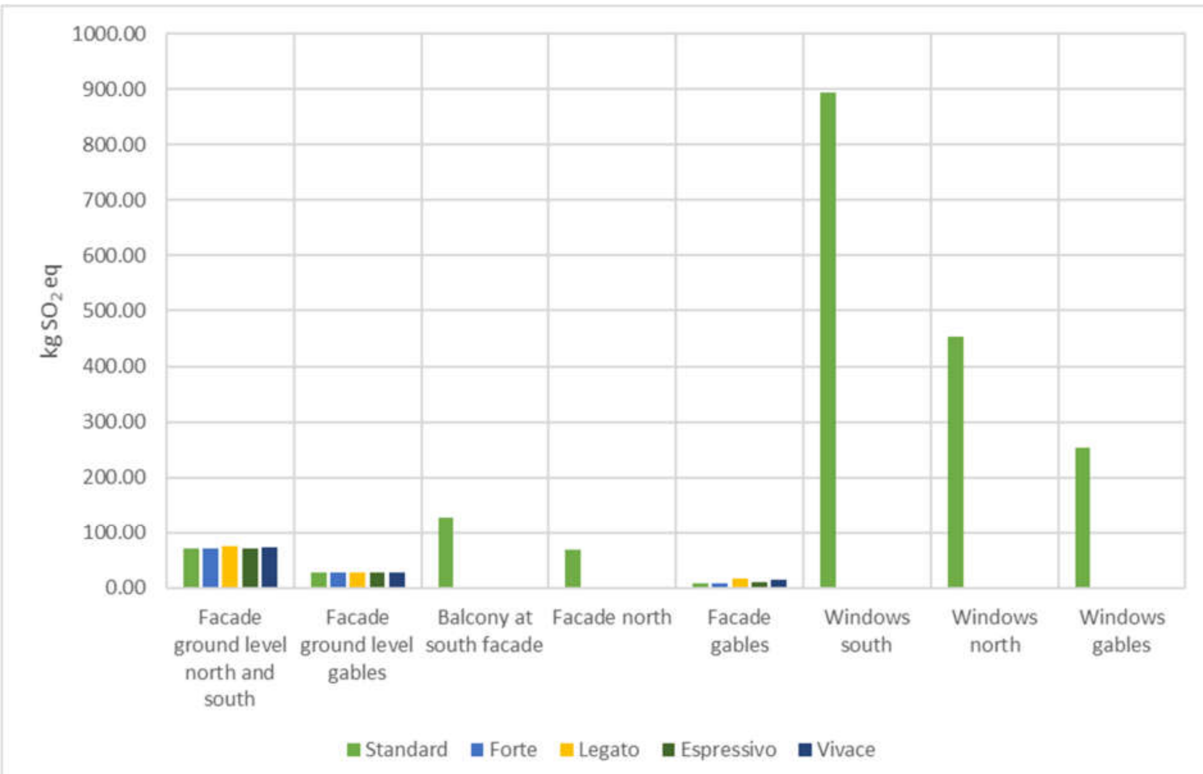


Figure 4.2.10 Avoided renovation materials Terrestrial Acidification

The final aggregated impacts between the scenarios are very similar, so the dynamic scenarios do not have a large impact on terrestrial acidification in relation to the avoided building materials. The Legato scenario will have the highest impact resulting in 55.8 European person equivalents while the standard scenario with the lowest impact will result in 55.4 European person equivalents in relation to photochemical oxidant formation over the 50 year period. The windows and the glazing at the balcony façade are responsible for around 90 % of all impacts related to terrestrial acidification.

4.2.2.5. Freshwater eutrophication

The results in figure 4.2.11 shows that the impact from the gables will be negative. The impact in the production phase of the expanded polystyrene are very low, while the end of life stages have a very high negative impact due to the incineration of the polystyrene. This is also the reason the impacts in the gable facades are very dependent on the energy scenarios.

The production impacts in the ground level facades are much higher than the gable facades. This larger impact is related to the production of mortar and the stone tiles. The negative impact in the end of life stages are also smaller, which might be related to the crushing and landfill of stone tiles and mortar. Windows are still the major contributors of impacts. The negative impacts in the end of life is larger, which indicates that the aluminum is responsible for a larger share of the impact than in the other impact categories.

The north facade also contains aluminum. In the previous four impact categories the impact was larger for the balcony glazing and for the north wall. In freshwater eutrophication the impact for the north facade is larger than for the glazing at the balconies, which does not contain aluminum.

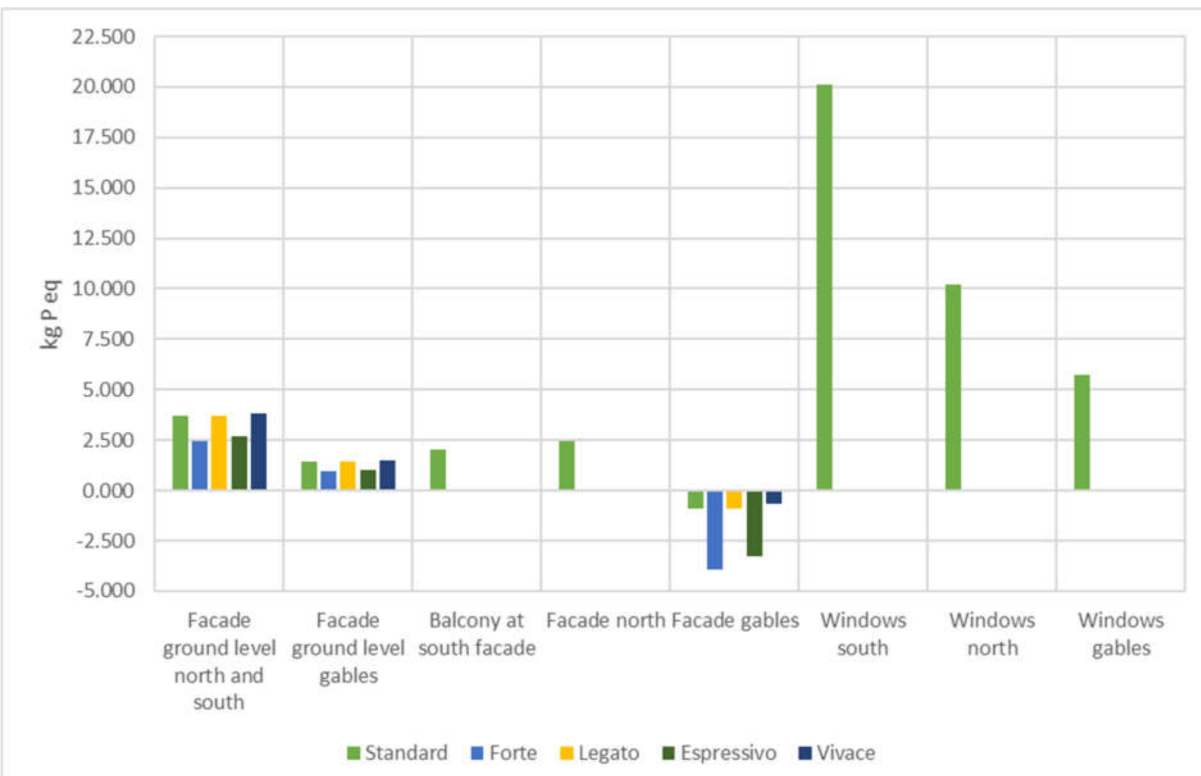


Figure 4.2.11 Avoided renovation materials Freshwater Eutrophication

The impacts were strongly influenced by the energy scenarios related to freshwater eutrophication. This time the Vivace scenario has the highest impact resulting in 108.8

European person equivalents while the standard scenario with the lowest impact will result in 96.4 European person equivalents in relation to Freshwater eutrophication over the 50-year period.

4.2.3. Avoided energy

The avoided impacts from electricity are simulated over a period of 50 years. All impact results for the dynamic scenarios shows a changing in the impact from the first-year unit the year 2050. After 2050, the annual impacts for the dynamic scenarios will be constant until 2069. The high voltage energy mix is the standard Swedish electricity process from OpenLCA. The impact from the high voltage electricity mix is not dynamic, so the impacts will be constant over the 50 years.

4.2.3.1. Climate Change

The results for the climate change impact in figure 4.2.12 shows that the impact for scenario 2 is larger than the corresponding impacts for scenario 1. These results were expected because the annual electricity input for Canopy scenario 2 are 33179 kWh higher than in scenario 1. The electricity impacts are avoided impact so Canopy scenario 2 performs better than scenario 1 in all four future energy scenarios and the standard non-dynamic electricity grid.

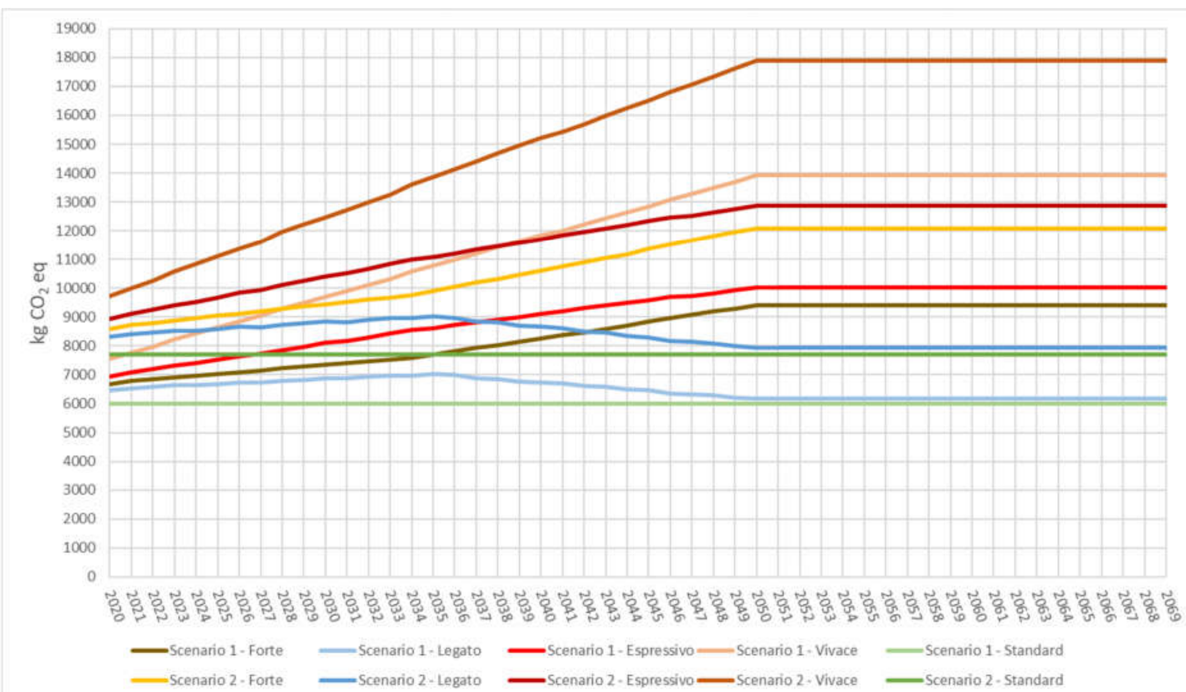


Figure 4.2.12 Avoided impact from energy scenarios to Climate Change

The results in figure 4.2.12 show that three of the future energy scenarios will cause a rise in the impact to climate change. This result can seem wrong, since there is a common understanding that we need a greener energy system in the future. The reason is that the Swedish energy mix is based on a large share of nuclear electricity production, which was around 41.5 % in 2014 (Swedish Energy Agency, 2016). Nuclear power production is very efficient in terms of CO_2 emissions compared with other energy sources. Nuclear power production will be decreased in all four future energy scenarios which will result in an increased impact. The share of nuclear power from 2050 will be 0 % in Legato and Vivace, around 2 % in Espressivo and 39.2 % in Forte. The results showed that the impacts in the Legato scenario will increase until 2035, after which it will start to decrease and reach an impact limit that is lower than in 2020. The reason could be that the Legato scenario has the largest share of wind turbines, which is much higher than all other scenarios. The main energy sources in the Legato future energy scenario are hydropower and wind turbines, which together gives the lowest impact in terms of climate change.

The energy scenario with the highest impact in climate change over the period of 50 years is the Vivace scenario, with an aggregated impact of 597943 kg CO_2 equivalents for canopy scenario 1 and 768483 kg CO_2 equivalents for canopy scenario 2. This will correspond to 61.9 European person CO_2 equivalents for canopy scenario 1 and 79.5 European person CO_2 equivalents for canopy scenario 2 over a period of 50 years. The energy scenario with the lowest impact in climate change potential over 50 years are the standard non-dynamic electricity mix with an impact of 300076 kg CO_2 equivalents for canopy scenario 1 and 385661 kg CO_2 equivalents for canopy scenario 2. This will correspond to 31.1 European person CO_2 equivalents for canopy scenario 1 and 39.9 Europe person CO_2 equivalents for Canopy scenario 2 over a period of 50 years.

4.2.3.2. Ozone depletion

There are 2 future energy scenarios that will cause a decrease in ozone depletion impact and two future energy scenarios that will cause an increase. It appears from figure 4.2.13 that the annual impact in the Legato scenario will be reduced by more than 50 % of the impact from 2020 to 2050. Due to the large reduction in impact, the Legato scenario will end up with the lowest annual impact.

When looking at climate change impacts, the Vivace scenario was the highest emitting scenario. In ozone depletion impacts, however, the Forte scenario is now the scenario with the highest impacts. The difference in ozone depletion impact between the two scenarios are rather small, which makes it difficult to predict a tendency. One of the main differences between the two scenarios is the share of nuclear power which becomes 0 % in the Vivace scenario and 39.2 % in the Forte scenario.

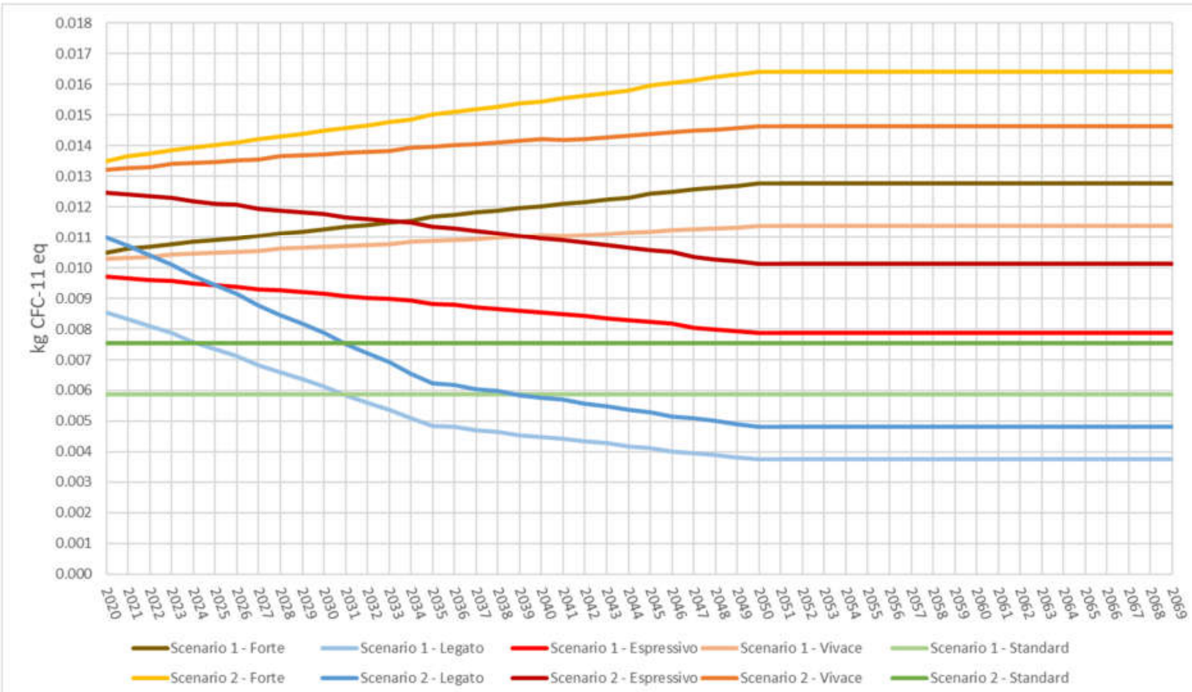


Figure 4.2.13 Avoided impact from energy scenarios to Ozone Depletion

The Forte energy scenario will have the highest aggregated impact resulting in 27.4 European person CFC-11 equivalents for the canopy 1 and 35.3 European person CFC-11 equivalents for the canopy 2 over 50 years. The Legato energy scenario will have the lowest aggregated impact resulting in 11.3 European person CFC-11 equivalents for the canopy 1 and 14.2 European person CFC-11 equivalents for the canopy 2.

4.2.3.3. Photochemical oxidant formation

Figure 4.2.14 shows that the Vivace scenario will have a large increase in photochemical oxidant formation. The Espressivo scenario will also result in a large increase of the impacts. It can be difficult to determine the reason for the increased impact without further investigation of the dynamic system. But some of the similarities between the two systems are that the nuclear power is reduced to almost 0, while the incineration of waste materials in small combined heat- and power plants are increased.

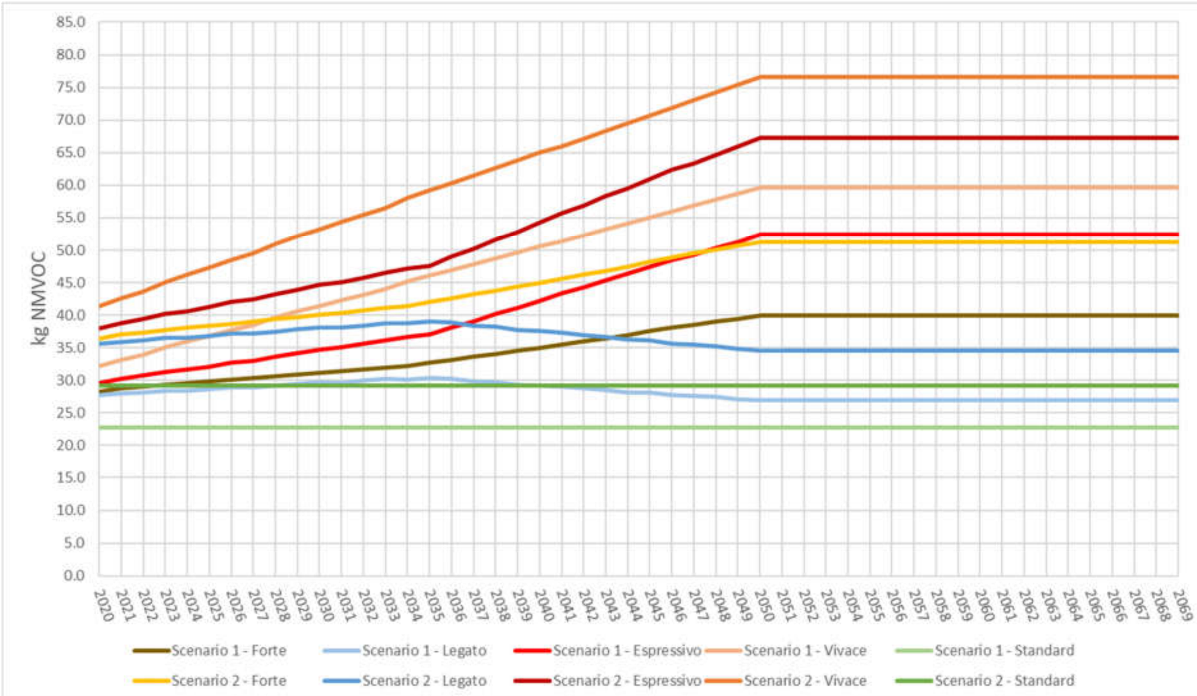


Figure 4.2.14 Avoided impact from energy scenarios to Photochemical Oxidant Formation

The Vivace energy scenario will have the highest aggregated impact resulting in 45 European person kg NMVOC equivalents for canopy 1 and 57.8 European person NMVOC equivalents for canopy 2 over 50 years. The Standard energy scenario will have the lowest aggregated impact resulting in 20 European person NMVOC equivalents for canopy 1 and 25.7 European person NMVOC equivalents for canopy 2.

4.2.3.4. Terrestrial acidification

Figure 4.2.15 shows that the impact from the standard system are much lower than all the dynamic systems. For example, the impacts from the Vivace scenario are 3.5 times higher than impacts from the standard energy scenario in the period from 2050 to 2069. The standard scenario is based on the Swedish energy mix in 2008. If the linear tendency of the increased impacts in the dynamic scenarios is started in 2008, the impact in 2008 will be around the same impact level as the standard system.

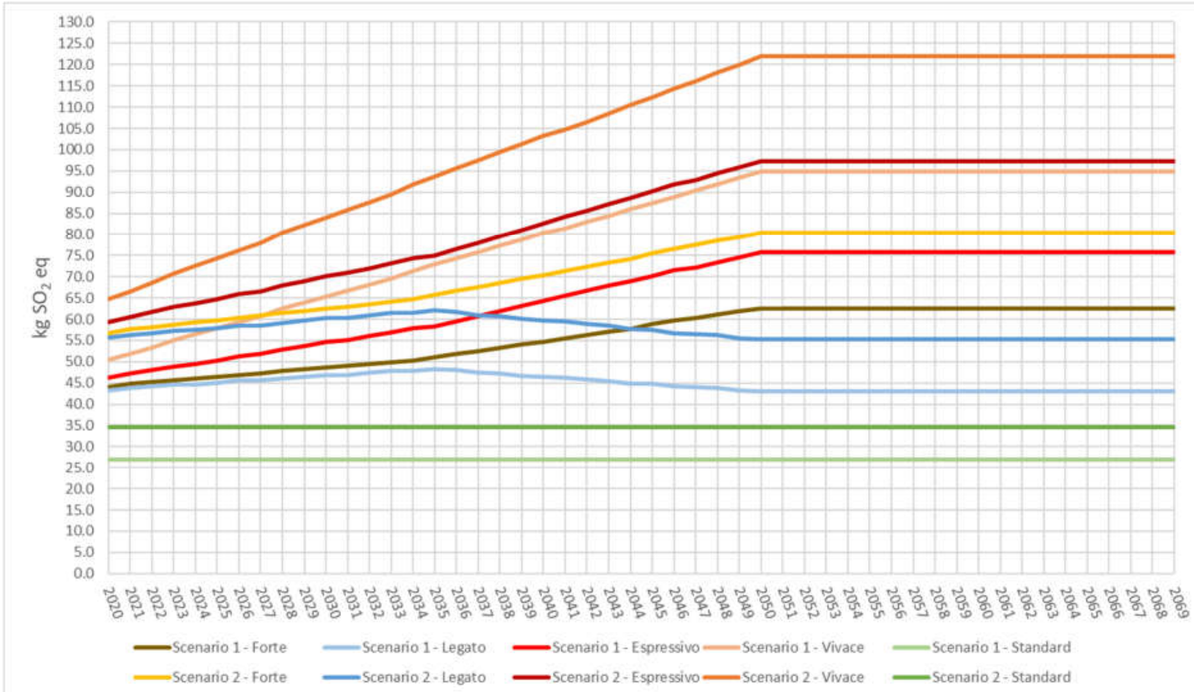


Figure 4.2.15 Avoided impact from energy scenarios to Terrestrial Acidification

Legato is still the dynamic energy scenario with the lowest impact. The Legato scenario has behaved equally in terms of increasing and decreasing impact in climate change, ozone depletion, photochemical oxidant formation and terrestrial acidification.

The Vivace energy scenario will have the highest aggregated impact resulting in 118 European person SO_2 equivalents for canopy 1 and 157.7 European person SO_2 equivalents for canopy 2 over 50 years. The Standard energy scenario will again have the lowest aggregated impact resulting in 39.2 European person SO_2 equivalents for canopy 1 and 50.4 European person SO_2 equivalents for canopy 2.

4.2.3.5. Freshwater eutrophication

One of the most interesting findings from the simulation of the freshwater eutrophication is that the Legato scenario is no longer the dynamic scenario with the lowest impact. The Forte scenario has the lowest share of wind turbines, which are decreasing until 2050.

All dynamic scenarios will have an increasing in impacts, but the impacts from the Forte scenario stop increasing and flatten out in 2035, which is the same year that the nuclear power production in the Forte scenario becomes 0 %.

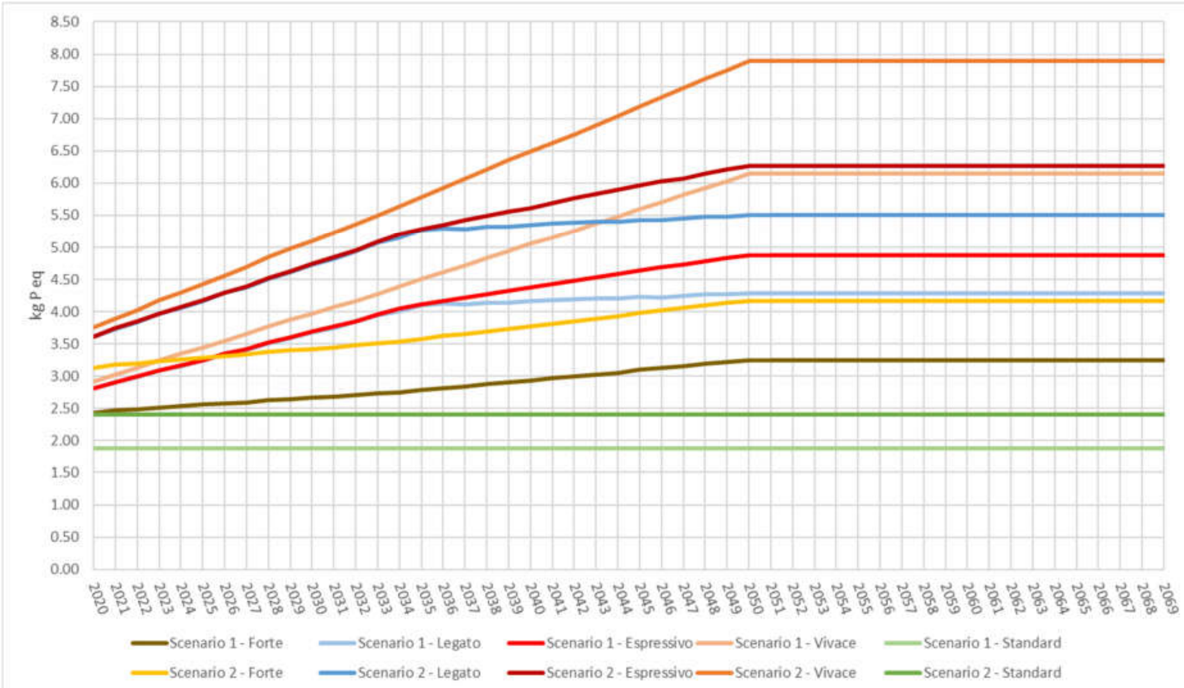


Figure 4.2.16 Avoided impact from energy scenarios to Freshwater Eutrophication

Again, the Vivace energy scenario will have the highest aggregated impact, resulting in 619 European person P equivalents for canopy 1 and 795.6 European person P equivalents for canopy 2 over 50 years. The Standard energy scenario will also – as before - have the lowest aggregated impact resulting in 225.9 European person P equivalents for canopy 1 and 290.3 European person P equivalents for canopy 2.

4.2.4. Break-even point

The break-even point is the point where the avoided impacts become larger than the environmental impacts. This break-even point can be found by aggregating the impact with the avoided impacts that will have a negative value. Impacts have a positive value, so the break-even point will occur when the graph crosses the x-axis and the values become negative, which means that the impact from that point will be an avoided impact.

4.2.4.1. Climate Change

Figure 4.2.17 shows that the break-even point for Scenario 1 will occur instantly. The reason is that the avoided impact from renovation materials is around 25 % higher than the impacts from the canopy. The initial impact from the canopy in Scenario 2 is higher than the impact from the avoided renovation materials. The break-even point for Scenario 2 will occur within a year of the renovation. The graphs have a large increase in avoided impact at year 2045 and 2070. This is due to the replacement of some of the materials in the canopy, and the renovation. The impact from the materials in the canopy is still smaller than the avoided impact from the replacement of renovation materials, which gives the increase in avoided impact in both canopy scenarios. The large increase in avoided impact at year 2070 will mainly happen due to the incineration of wood for production of district heating.

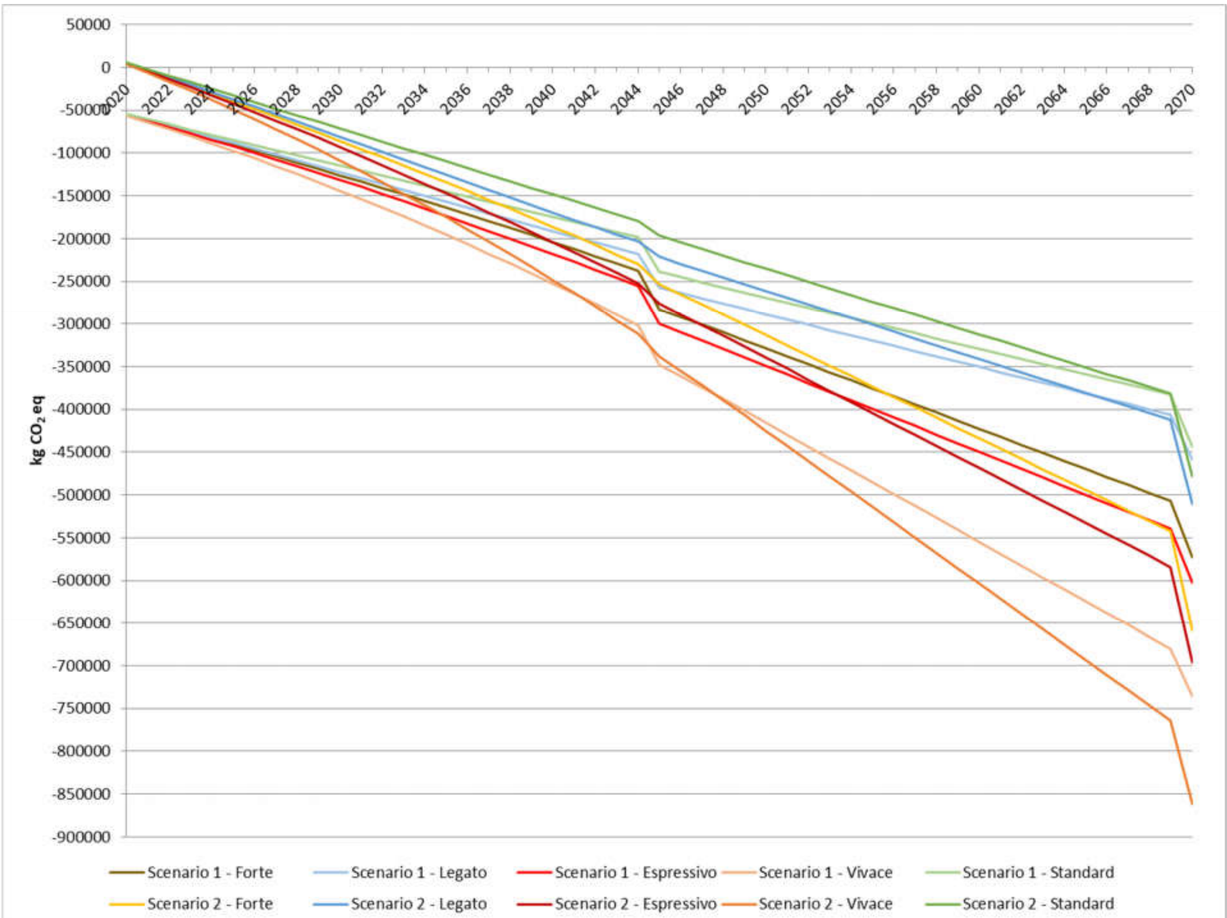


Figure 4.2.17 Annual Climate Change impacts over 50 years

The differences between the two canopy scenarios in relation to the aggregated avoided impacts in year 2070 are small for some of the energy scenarios while it is larger for some other. The tendency is that the differences are very much dependent on the impact of the energy scenarios, which also is important for how large the final aggregated avoided impact is. Energy scenarios with a small impact will give small variations between the canopy scenarios and smaller aggregated avoided impacts. Energy scenarios with large impacts will give larger differences between the canopy scenarios and large aggregated avoided impacts. Canopy scenario 2 will have the largest aggregated avoided impacts for all energy scenarios.

The Standard energy scenario will have the lowest aggregated avoided impact for both canopy scenarios. The avoided impact in 2070 for the canopy 1 scenario will be 443561 avoided kg CO_2 equivalents corresponding to 39.6 European person CO_2 equivalents. The avoided impact in

2070 for the canopy 2 scenario will be 478422 avoided kg CO_2 equivalents corresponding to 42.7 European person CO_2 equivalents.

The Vivace scenario will have the highest aggregated avoided impact of 735394 kg avoided CO_2 equivalents corresponding to 65.6 European person CO_2 equivalents for the canopy 1 scenario. Canopy scenario 2 will result in 861244 kg avoided CO_2 equivalents corresponding to 76.8 European person CO_2 equivalents.

4.2.4.2. Ozone depletion

All dynamic energy scenarios will reach the break-even point within the first year for the canopy scenario 1. The standard energy scenario will reach the break-even point within the second year. The impacts from the canopy are twice as high than the avoided impacts from renovation materials the first year.

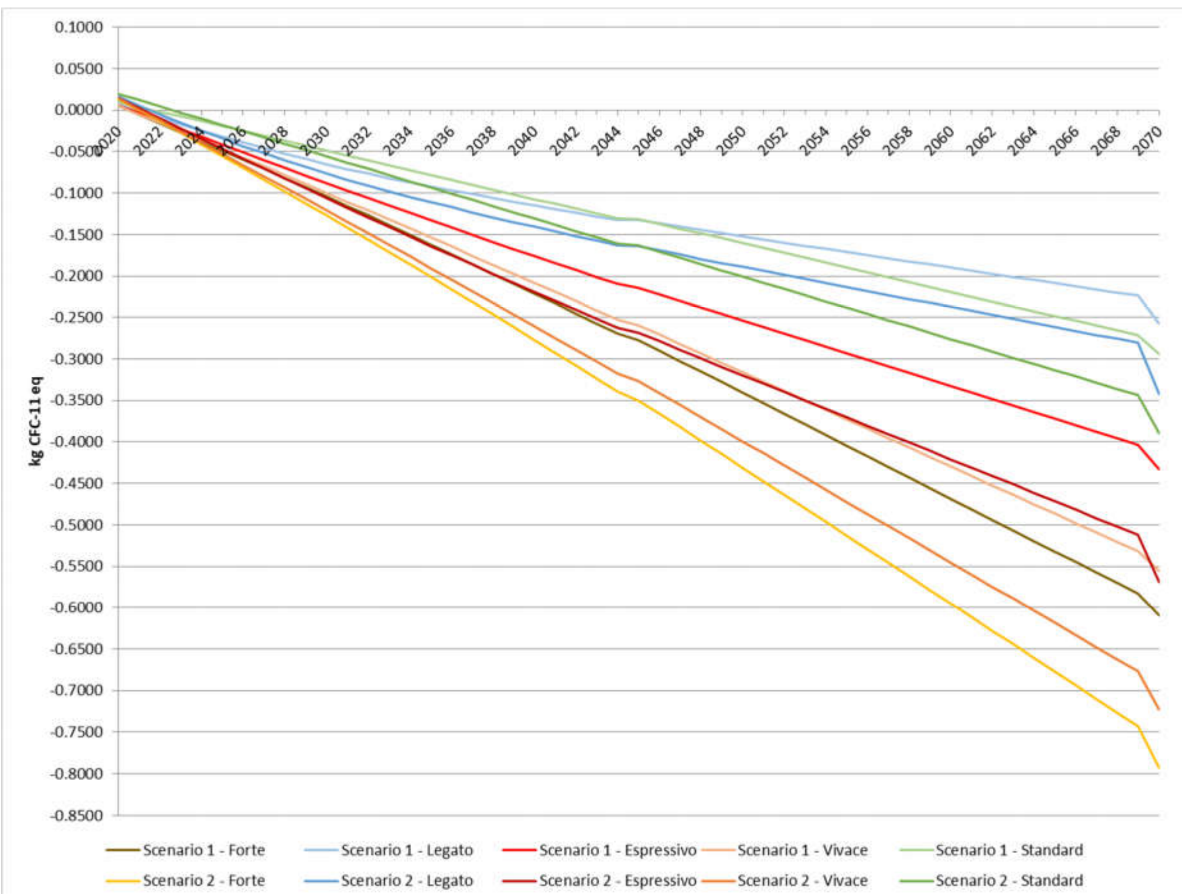


Figure 4.2.18 Annual Ozone Depletion impacts over 50 years

The energy scenarios have a high impact on avoided impact from ozone depletion, because the avoided impacts from the electricity are rather high and occur every year.

As shown in figure 4.2.18, the increase in avoided impact is smaller in 2045 because the impact from the canopy materials are around 3-5 times larger than the avoided renovation materials dependent on the energy and canopy scenario. The avoided impacts will still increase in 2045 because the avoided impact from energy are typically larger.

The aggregated avoided impact for ozone depletion is generally low for both canopy scenarios. The Legato energy scenario will have the lowest aggregated avoided impact due to ozone depletion. The avoided impact in 2070 for the canopy 1 scenario will be 0.2575 avoided kg CFC-11 equivalents corresponding to 11.7 European person CFC-11 equivalents. The avoided impact in 2070 for the canopy 2 scenario will be 0.3422 avoided kg CFC-11 equivalents corresponding to 15.5 European person CFC-11 equivalents.

The Vivace scenario will again have the highest aggregated avoided impact of 0.5556 kg avoided CFC-11 equivalents corresponding to 25.2 European person CFC-11 equivalents for the canopy 1 scenario. The canopy scenario 2 will result in 0.7232 kg avoided CFC-11 equivalents corresponding to 32.9 European person CFC-11 equivalents.

4.2.4.3. Photochemical oxidant formation

Impact from canopy and avoided building materials has a much higher influence on the break-even point for photochemical oxidant formation as shown in figure 4.2.19. In canopy scenario 1 the avoided impact from renovation materials is larger than the impact from the canopy in year 2020. This means that the break-even point will occur instantly for all the energy scenarios in relation to canopy scenario 1.

In canopy scenario 2, the impact from the canopy is larger than the avoided impact from building materials. The break-even point will therefore be much more dependent on the avoided impact for the energy. Thus, the break-even point between the different energy scenarios is more spread out for the canopy 2 scenario, where the first break-even point will occur in 2024 for the Espressivo scenario. The break-even point for the Standard energy scenario will happen in 2026.

The tendency of the increase of avoided impacts and the spread between the scenarios are very like the climate change impact category. The Standard energy scenario will have the lowest aggregated avoided impact in relation to Photochemical oxidant formation. The avoided impact in 2070 for canopy 1 scenario will be 1588.9 avoided kg NMVOC equivalents corresponding to 28 European person NMVOC equivalents. The avoided impact for the canopy 2 scenario will be 1759.6 avoided kg NMVOC equivalents corresponding to 31 European person NMVOC equivalents.

The Vivace scenario will have the highest aggregated avoided impact of 3000.6 kg avoided NMVOC equivalents corresponding to 52.8 European person NMVOC equivalents for the canopy 1 scenario. Canopy scenario 2 will result in 3586.9 kg avoided NMVOC equivalents corresponding to 63.1 European person NMVOC equivalents.

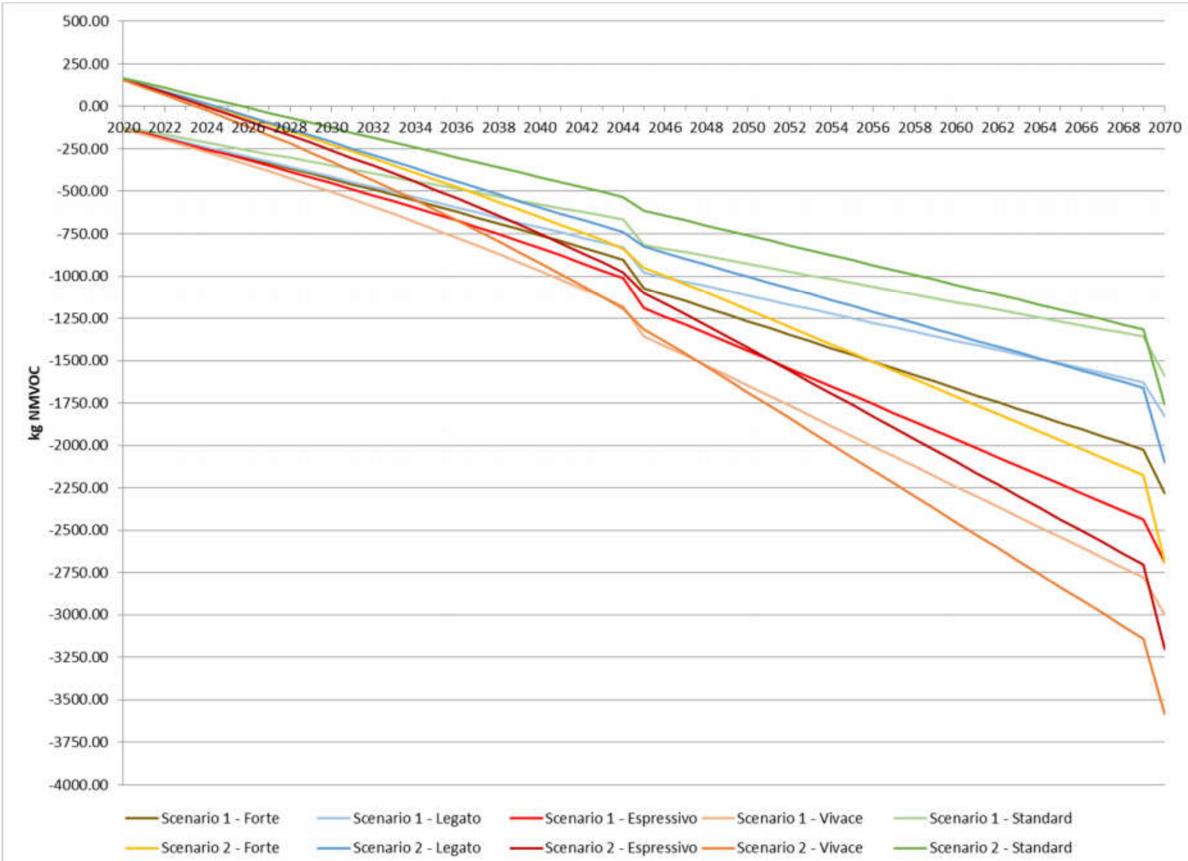


Figure 4.2.19 Annual Photochemical Oxidant Formation impacts over 50 years

The deviation between the energy scenarios with the lowest and highest impact is more than 88 % for the scenario 1 canopy and more than 100 % for canopy scenario 2.

4.2.4.4. Terrestrial acidification

The break-even point for terrestrial acidification will occur instantly for all scenarios. The reason is that the avoided impact from building materials are higher than the impact from the canopy. In the scenario 1 canopy, the deviation in impact is around 40 % in the first year. The deviation is smaller for the scenario 2 canopy, which is why all energy scenarios related to canopy 2 originate closer to the x-axis.

Figure 4.2.20 shows a large increase in the avoided impacts at year 2045, where materials replacement occurs. The impact from the avoided replacement of building materials is much higher than the impact from the canopy materials. The deviation in 2045 is around 50 % for all canopy 1 scenarios and 35 % for all canopy 2 scenarios.

The Standard energy scenario will, once again, have the lowest aggregated avoided impact for both canopy scenarios. The aggregated avoided impacts for the canopy 1 scenario will be

2492.3 avoided kg SO_2 equivalents corresponding to 72.5 European person SO_2 equivalents. The avoided impacts for the canopy 2 scenario will be 2618.1 avoided kg SO_2 equivalents corresponding to 76.2 European person SO_2 equivalents.

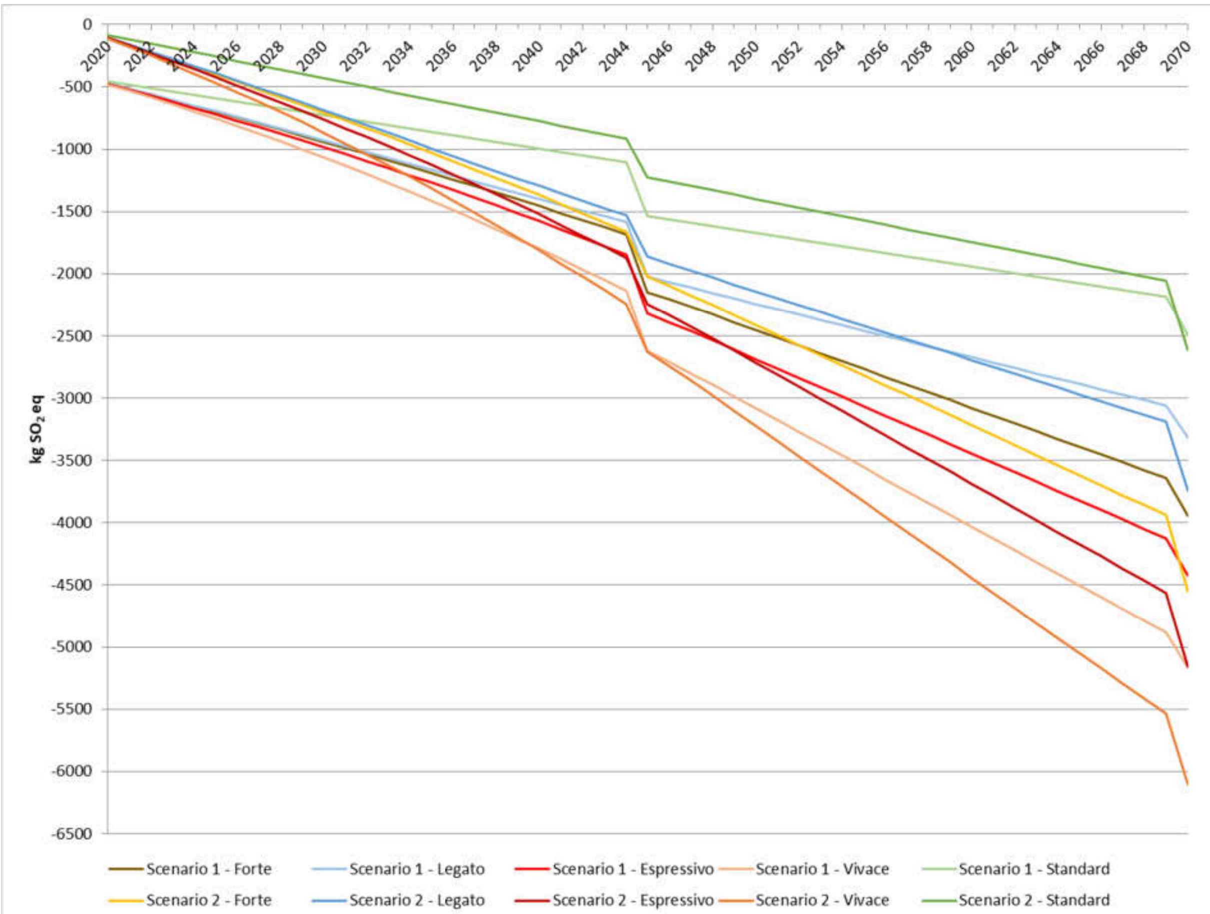


Figure 4.2.20 Annual Terrestrial Acidification impacts over 50 years

The Vivace scenario will have the highest aggregated avoided impact of 5164.4 kg avoided SO_2 equivalents corresponding to 150.2 European person SO_2 equivalents for the canopy 1 scenario. Canopy scenario 2 will result in 6099.7 kg avoided SO_2 equivalents corresponding to 177.4 European person SO_2 equivalents.

4.2.4.5. Freshwater eutrophication

The big difference between freshwater eutrophication and the other impact categories is that the impact from the starting point is much higher, and that the break-even point will occur much later. One of the reasons for the large differences is that the impact from the avoided energy are much lower than the impacts from the canopy and the avoided impacts from renovation materials. The Legato, Espressivo and Vivace canopy 1 scenarios will have the break-even point in 2025 and be the first scenarios that reach the break-even point. The canopy 2 Standard scenario will reach the break-even point in 2040, and will be the last scenario to reach the break-even point.

The materials replacement in 2045 will cause an increase in avoided impacts for all canopy 1 scenarios and a decrease in avoided impacts for all canopy 2 scenarios.

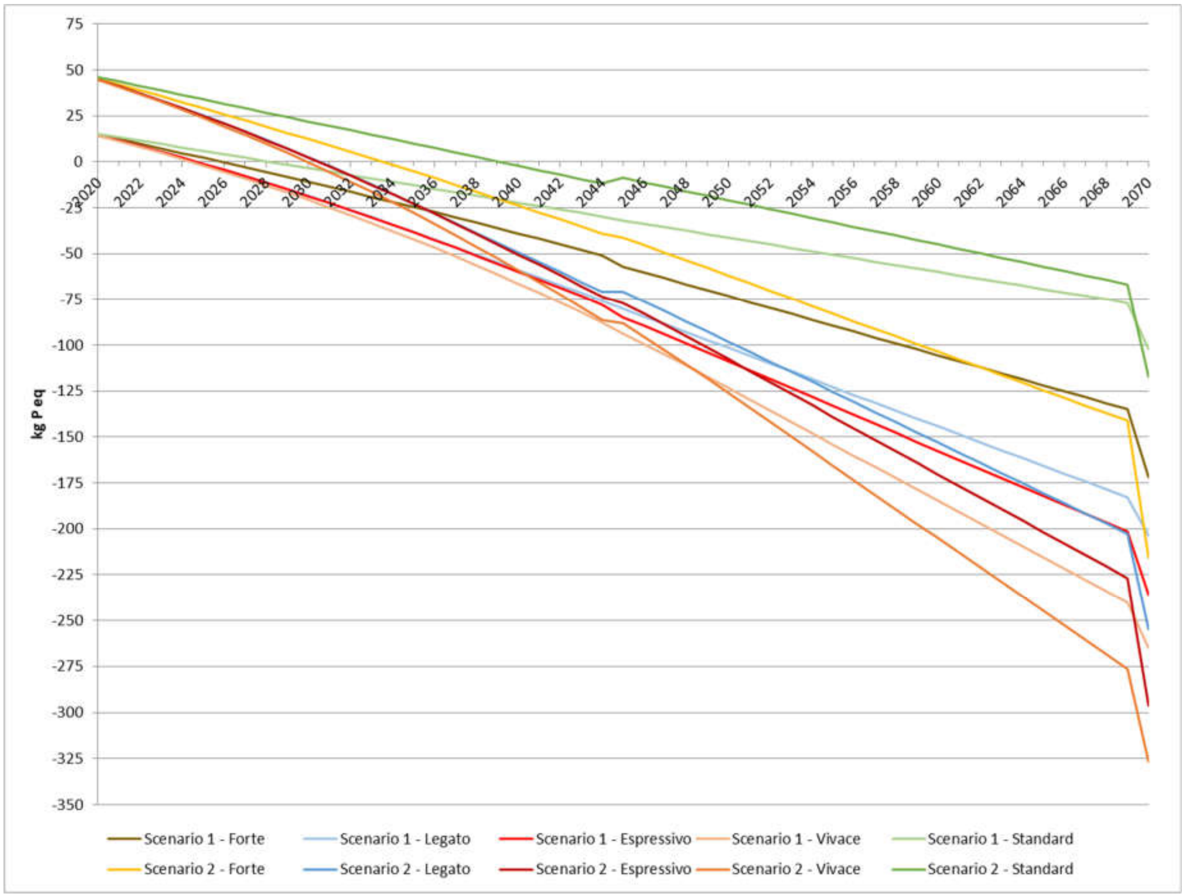


Figure 4.2.21 Annual Freshwater Eutrophication impacts over 50 years

The Standard energy scenario will again have the lowest aggregated avoided impacts. The aggregated avoided impacts for the canopy 1 scenario will be 102.4 avoided kg P equivalents corresponding to 246.9 European person P equivalents. The avoided impacts for the canopy 2 scenario will be 117.2 avoided kg P equivalents corresponding to 282.5 European person P equivalents.

The Vivace scenario has had the highest impact in all impact categories. The same applies for Freshwater eutrophication, where the Vivace scenario will have the highest aggregated avoided impact of 264.8 kg avoided P equivalents corresponding to 638.4 European person P equivalents for the canopy 1 scenario. Canopy scenario 2 will result in 326.7 kg avoided P equivalents corresponding to 787.6 European person P equivalents.

4.3. Sensitivity analysis

Tables with the results of the calculated sensitivity ratio can be found in appendix K. The results show a large distribution in sensitivity between the different processes. The standard scenarios give the larges sensitivity ratio in almost all processes.

Some of the sensitivity ratios are positive and some are negative. The reason for this is that the sensitivity ratio is calculated based on the final aggregated avoided impact, which is also used to find the break-even point. When the value of the parameters is increased with 10 %, it will result in an increased aggregated avoided impact for some processes, which gives a sensitivity ratio with a positive value, while other processes will result in a decrease in the aggregated avoided impact, which will give a sensitivity ratio that is negative.

If the sensitivity ratio is close to 1, it will mean that the relationship between input and output are almost linear. So, if the input value is changed with 10 %, the final output to the model will also cause a change of 10 % at a sensitivity ratio of 1. If the sensitivity ratio is below 0.2, the relation between input and output of the model will be very low for the process.

4.3.1. Climate Change

Electricity scenarios are the processes with the larges sensitivity ratio in relation to climate change. The sensitivity ratio will vary between the two canopy scenarios and the different energy scenarios. The distribution in sensitivity ratio for the energy scenarios will be in the range of 0.7-0.9, which means that the energy scenarios have a high impact on the results of the model.

The sensitivity from facade materials was generally very low. All facade materials have a sensitivity ratio below 0.05, while the windows in the north and south facade has a sensitivity ratio that is in the range of 0.1-0.2. The sensitivity for the canopy materials is much larger than for the facade. The sensitivity for the glazing in the second canopy scenario is much higher than for the first canopy scenarios. This difference might be related to the increased amount of glazing in the second canopy scenario. Materials with a medium sensitivity in the canopy are ETFE and steel, which have a sensitivity ratio in the range of 0.15-0.41. The sensitivity ratio for silicone sealing, Timber, aluminum and pumps was either low or very close to zero.

4.3.2. Ozone depletion

In relation to ozone depletion, the sensitivity ratio for all building and canopy materials was close to zero. The processes with the highest sensitivity were, once again, the electricity scenarios. The sensitivity ratios are in the range of 0.92-1.0, which is rather high. This means that, for some of the energy scenarios, there will be a 1 to 1 relation between input to the process and the final aggregated impacts.

4.3.3. Photochemical oxidant formation

The processes' sensitivity ratio in relation to photochemical oxidant formation are very similar to the sensitivity in climate change. The largest difference is that facade windows and the canopy glazing are more sensitive to changes in input. The sensitivity ratio for glazing in the second canopy scenario is almost 1 for the Standard scenario, while it is 0.46 for the Vivace scenario. The reason for the big difference is that the final aggregated impact in the Vivace scenario is almost twice the impact of the standard scenario. The Standard scenario is more sensitive to changes in inputs, because while the value of changes is the same for the two scenarios, the percentage of change will be much higher for the Standard scenario, due to the low final aggregated impact.

4.3.4. Terrestrial acidification

The glazing in the second Standard canopy scenario will also give the largest sensitivity in relation to terrestrial acidification. The sensitivity ratio is 1.15 which means that the change in the final aggregated impact is larger than the changed input parameter. The sensitivity ratio for the glazing in the first canopy scenario are very small, around 0.1, compared to the second canopy scenario.

The standard scenario will give the highest sensitivity ratio in relation to all material processes. This is not the case in relation to the energy processes, where the Standard scenarios will cause the lowest sensitivity ratio. The reason is that, if the annual energy consumption is increased with 10 % for the scenarios with a high impact, it will cause a larger output, which also means a larger sensitivity.

4.3.5. Freshwater eutrophication

The glazing in the canopy will still result in a large sensitivity ratio in relation to freshwater eutrophication, but this time the energy parameters will cause the largest sensitivity ratio, which will be in the range of 0.88-1.03. This time, the standard energy scenario is responsible for the largest sensitivity ratio, which is the direct opposite of the other impact categories. This is also applied for all material processes both for the building and canopies.

The sensitivity of the pump parameter is, once again, very close to zero, which was also the case in the four other impact categories, so the impact from the pumps is very limited in the model. The impact assessment showed that the impact contribution from the pump was very small compared to the other canopy materials. It can be argued that the impact and sensitivity from the pumps are so small that they can be neglected.

5. Discussion

Large scale LCA studies are always affected by limitations. Most of these limitations can be related to time and money. Proper data is mostly one of the biggest limitations in LCA studies, but this limitation can normally be handled with the right amount of time and money. Data collection can be very time consuming in the early phases of the LCA studies, which was also the case in this project, where the first two months of the project were used for gathering data, e-mail correspondence, telephone calls and travels to Sweden. It was not possible to collect all the required data, such as information about building systems, and detailed LCA studies of the ETFE environmental properties. The latter lack of data was handled by assumptions, which will, of course, never represent the real case with 100 % accuracy.

No projects have infinite time, and this project was limited to 5 months. There were many areas of interest regarding this project, but due to the limited time schedule, not all areas could be investigated in this project. This project has investigated two different ETFE canopies, but it is very likely that a real EKO-canopy will be a glazing construction as in the EKO-canopy proposal by White. A glass canopy will be much heavier than the ETFE canopy, which means that a glass canopy cannot use the same minimal surface as the ETFE canopy. It would have been too time-consuming to develop two different canopy layouts with different materials composition and structural system, and it would also be difficult to compare the two canopies because they will be so different.

The report about the four Swedish energy futures was found during the literature studies concerning the Swedish energy mix. This report changed the entire scope of the project. The original main scope was to develop and optimize an EKO-canopy proposal based on previous studies of the Canopy from DTU. The Swedish energy scenario report gave the opportunity to investigate several possible futures instead of only one. This was an interesting study because we cannot predict the future with 100 % certainty. This study can then demonstrate the differences in future predictions and how much they affect the environmental impact over 50 years.

Energy simulation was not a part of the scope. The first plan was to use the energy consumption calculated in a previous EKO-Canopy study. This data turned out to be insufficient, because they were not based on the standard renovation concept from the other apartment blocks. The data foundation in this project was larger than in the previous project, so it also turned out that some of the assumption in the previous projects did not represent the real renovation case. It was then decided to make new energy calculations. The problem with large scale dynamic energy simulations is that they consume a lot of time. Normally, energy calculations would be the main scope of an entire master thesis. This study was still limited to 5 months, so some of the topics from the old scope had to be removed. It was then chosen to remove the life cycle costing from the study, as well as the social sustainability. The life cycle costing has been covered briefly in another project, where it was estimated that a ETFE canopy will cost 3.3 million euros, while a total facade renovation will cost 1.6 million euros (Knudsen, 2016). It is important to mention that the facade renovation used for this estimation does not covers the standard facade renovation used at Dragonvägen.

The building blocks at Dragonvägen, also called Fyrklövern, are used as a case study about social sustainability in another DTU master thesis project (Otovic, 2016). The case study does not cover a renovation concept or the EKO-Canopy proposal by White. There is no detailed study of the social sustainability in direct relation to the EKO-Canopy, but it can be expected that the EKO-Canopy will gives the same social properties as most glass covered areas.

From the beginning, it was decided that the LCA should be carried out in OpenLCA instead of some of the more conventional LCA tools as GaBi or SimaPro. The main goal was to get some experience with open source LCA tools. It became clear during the process with the system modelling in OpenLCA that the program had some limitations in comparison with the conventional tools. The presentation of results in OpenLCA is limited to the final output of the completed system, so it is not possible to get data on the processes in the beginning of the system. This problem was handled by splitting up the system into many small processes. The data is the exported from OpenLCA into Excel for further handling. This way of working with results in many different programs is very time-consuming. There will be a lot of cross references between the Excel documents and the OpenLCA data sheets, which carries a large risk in case of errors and misplacement of data. The benefit with OpenLCA is that it is free and that you pay for data instead. This benefit will become much smaller in a conventional company application if the program is much more time consuming. Because OpenLCA is open source, is it possible to develop plugin that can minimize or remove the problem with the data handling. Another problem with OpenLCA and dynamic scenarios is that you must redo your dynamic project scenario if you want to change the processes used in the scenario. This is also a very time-consuming step, especially in the dynamic energy scenarios, where each scenario consists of several hundred values that need to be typed in manually. This process can take a whole day when you have several scenarios for different energy sources.

One of the main problems with the LCA was lack of material processes in the Ecoinvent database. Material processes for the ETFE is not included in the database, so another material had to be used instead of ETFE. Because there is no process data about ETFE, is it not possible to know how large a difference for the result this assumption will have. The end of life flows can have a major impact on the environment result from the different processes. The end of life data for reuse of materials is very limited, and it became clear during the project that most of the processes named with recovery only cover landfill or incineration of materials and not recovery of materials for reuse. This is of course a major problem in the database, which also create a lot of limitations in the end of life stages.

At last is it important to mention that the results in this project are based on a case study, and cannot be directly applied in other cases with the same results as outcome. Material properties, renovation concept and energy use can change for different locations and countries. The dynamic energy grid is also based on the Swedish system, which can vary a lot even within the Nordic countries.

6. Conclusion

The design of the canopy showed a large increase in the glazing area if the canopy also covers the gables of the building block. The structural construction will also be increased, because the canopy will become heavier when more glazing is installed. The glazing is installed at the ground level to protect the upper ETFE cushion system.

The investigation of the renovation of two of the building blocks showed that the renovation concept applied in the buildings is a typical standard renovation that is used in many high-rise buildings in Sweden from the Million Homes Programme. The level of insulation in the old buildings was very low or none. All surfaces in the new building had to be insulated with around 80-100 mm of insulation. All old metal facade cladding was removed and replaced with facade plaster. The main heating source was changed from district heating to a heat pump that can recovery heat from the extracted air from the apartments. District heating can still be used during peak loads in the winter. The renovation of all facades facing the canopy can be avoided. The external surface layer of the facades facing the canopy should still be renovated due to the bad condition of the surface material. The avoided renovation materials were mainly windows, XPS and EPS insulation and stone mineral wool.

The results from the energy simulation showed that an energy saving can be obtained when adding the canopy to the building blocks. The canopy in scenario 1, which covers one facade of the building block, will result in an annual energy saving of 9.3 kWh/m^2 floor area per year. The scenario 2 canopy will result in an annual energy saving of 12 kWh/m^2 floor area per year. The energy saving will mainly be electricity for the heating pump. The electricity consumption for the blowing stations to the ETFE system, was shown to be very low compared to the total energy consumption for both apartment blocks.

The indoor climate simulation of the canopy showed that an acceptable temperature can be obtained in the canopy with only passive systems as natural ventilation, heat loss from apartments, thermal mass and solar radiation. The maximum temperatures in the summer will be around 30-35 °C. The minimum temperatures in the winter will be just above freezing.

The four energy futures for the Swedish energy grid were used in the study. The dynamic district heating scenarios were used in all flows that had district heating as an avoided next system product. The electricity scenarios were used to investigate the annual avoided electricity for the heat pump. The results from the impact assessment of the dynamic energy system showed that the avoided impact from all district heating scenarios will decrease during the next 50 years in terms of global warming potential. The impact assessment of the dynamic electricity scenarios showed an increase in impacts for several of the scenarios in all five impact categories used in this study.

In terms of avoided impacts from renovation materials, windows were the building part that contributed with the highest impact in all five impact categories. The impact from the extra insulation was relative small in relation to the impact from the windows, but the extra amounts of insulation was also small in relation to the insulation level in new buildings.

The sensitivity analysis showed that the windows and the energy were the most sensitive processes. This can be related to the large impacts from both windows and electricity.

The ETFE materials were the most dominating in terms of impacts in all five impact categories used in this study. The ETFE materials was not available in the Ecoinvent database, so the material in the model representing the ETFE was instead Polyvinyl fluoride. The polyvinyl fluoride material has some of the same properties as ETFE and is used for some of the same applications. The timber construction in the canopy contributed with a large negative impact in all impact categories. The negative impact comes from the incineration of the timber for production of district heating in the end of life stage. The dynamic district heating scenarios had a very large impact on the negative impact for timber. In some of the impact categories, there was a factor four difference between the district heating scenarios in relation to avoided impact from timber. The canopy in scenario 2 had the largest impact of the two canopy scenarios.

The annual aggregated impact from the canopy and avoided impacts from renovation materials and energy resulted in an overall avoided impact in all five impact categories. Both the canopy and the dynamic energy scenarios had a large impact on when the break-even point would happen. The impact in terrestrial acidification potential had a break-even point instantly because the avoided impact from renovation materials was larger than the impact for the canopy. Freshwater eutrophication impact had the latest break-even point, which happened after 19 years for the second canopy scenario with a standard non-dynamic energy grid. The last three impact categories would normally result in a break-even point within 2-5 years. The highest aggregated avoided impact that could be obtained in relation to climate change was 65.6 European person CO_2 equivalents for the canopy 1 scenario and 76.8 European person CO_2 equivalents for the canopy 2 scenario.

7. Future research perspectives

- Dynamic LCA studies of glass or polycarbonate canopy.
- Social sustainability in relation to the canopy concept.
- Economic sustainability in relation to the canopy concept.
- Detailed LCA studies of the ETFE material.
- End of life flows in relation to dynamic LCA. How to predict the future.
- Future production flows that can be used in dynamic LCA applications.
- Investigate other renovation concepts in relation to the EKO-canopy.
- Dynamic simulations with forecasted energy grid from other European countries.

References

Aagaard, N., Brandt, E., Aggerholm, S., & Haugbølle, K. (2013). *SBI 2013:30 - Levetider af bygningsdele ved vurdering af bæredygtighed og totaløkonomi.* Copenhagen: Statens Byggeforskningsinstitut.

ArchDaily. (2015, October 12). *Uppgrenna Nature House / Tailor Made arkitekter*. Retrieved from ArchDaily: http://www.archdaily.com

Birgisdóttir, H., & Rasmussen, F. N. (2016). *Introduction to LCA of Buildings.* Copenhagen: Danish Transport and Construction Agency.

Birgisdottir, H., Mortensen, L., Hansen, K., & Aggerholm, S. (2013). *SBi 2013:09 - Kortlægning af bæredygtigt byggeri.* Copenhagen: Statens Byggeforskningsinstitut.

COBAB. (2017, May 17). *FYRKLÖVERN*. Retrieved from COBAB: http://cobab.se/blog/projekt/fyrklovern/

Dall, O., Christensen, C. L., Hansen, E., & Christensen, E. H. (2003). *Ressourcebesparelser ved affaldsbehandlingen i Danmark.* København: The Danish Environmental Protection Agency.

Danish Standards. (2008). *Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values.* Charlottenlund: Danish Standards.

Danish Standards. (2008). *DS/EN ISO 14044:2008 - Environmental management – Life cycle assessment – Requirements and guidelines.* Copenhagen: Danish Standards.

Ebnesajjad, S. (2012). Technology and Applications of Pvf. I *Polyvinyl Fluoride* (s. 151-192). Elsevier Inc.

Energimyndigheten. (2017, March 2). *Fyra framtider*. Retrieved from Energimyndighete: http://www.energimyndigheten.se/klimat--miljo/fyraframtider/

European Commission Joint Research Centre. (2010). *ILCD Handbook - International Reference Life Cycle Data System.* Luxembourg: Publications Office of the European Union.

Goedkoop, M. (2013). *ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level.* Haag: Ministerie van volkshuisvesting ruimtelijke ordening en milieubeheer.

Hall, T., & Vidén, S. (July 2005). The million homes programme: A review of the great Swedish planning project. *Planning Perspectives*, s. 301-328.

Högberg, L., Lind, H., & Grange, K. (16. December 2009). Incentives for improving energy efficiency when renovating large-scale housing estates: A case study of the swedish million homes programme. *Sustainability*, s. 1349-1365.

Hu, J., Chen, W., & Zhao, B. (2017, January 30). Buildings with ETFE foils: A review on material properties, architectural performance and structural behavior. *Construction and Building Materials*, pp. 411–422.

Institut Bauen und Umwelt e.V. (2014). *EPD - Texlon-System.* Berlin: Institut Bauen und Umwelt e.V. (IBU).

Kling, R. (2012). *Lönsam energieffektivisering. Saga eller verklighet? För hus byggda 1950-75.* Stockholm: VVS-företagen.

Knudsen, M. K. (2016). *Investigation of EKO-Canopy energy renovation concept for Swedish million program apartment buildings - A case study of Dragonvägen.* Copenhagen: Technical University of Denmark.

Lind, H., Annadotter, K., Bjork, F., Hogberg, L., & Af Klintberg, T. (20. April 2016). Sustainable Renovation Strategy in the Swedish Million Homes Programme: A Case Study. *Sustainability*, s. 388.

Monticelli, C., Campioli, A., & Zanelli, A. (2009). Environmental load of EFTE cushions and future ways for their self-sufficient performances. I I. A. Structures, *Evolution and trends in design, analysis and construction of shell and spatial structures* (s. 754-766). Spain.

Moreno, E., Lévová, T., Bourgault, G., & Wernet, G. (2014). *Documentation of changes implemented in ecoinvent version 3.1.* Zurich: Ecoinvent Centre.

Mortensen, L., Birgisdottir, H., & Aggerholm, S. (2015). *SBI 2015:30 - Genbrug af byggevarer.* Copenhagen: Statens Byggeforskningsinstitut.

Ng, W. Y., & Chau, C. C. (August 2015). New life of the building materials- recycle, reuse and recovery. *Energy Procedia*, s. 2884 – 2891.

Otovic, A. P. (2016). *Designing social sustainability - Towards an operationalization of social sustainability concepts in an integrated design process.* Copenhagen: Technical University of Denmark.

Schlaich Bergermann Partner. (2000). *Training Academy Mont-Cenis Herne*. Retrieved from Schlaich Bergermann Partner: http://www.sbp.de/en

Sohn, J., Kalbar, P., Banta, G., & Birkved, M. (2016, January 20). Life-cycle based dynamic assessment of mineral wool insulation in a Danish residential building application. *Cleaner Production*, pp. 3243–3253.

Sundby naturhus. (2014). *Bengt Warne*. Hentet fra Sundby Naturhus: http://www.sundbynaturhus.se

Swedish Energy Agency. (2016). *Four Futures - The Swedish energy system beyond 2020.* Eskilstuna: Swedish Energy Agency.

Toftum, J., Petri, M., & Rønne, C. (2016, November). Det beboelige drivhus. *HVAC*, pp. 26-28.

Vila, L. F. (2016). *Parametric Structural Design - Integration of structural verifications in the early design phases.* Kongens Lyngby: Technical University of Denmark.

Appendix A: IDA ICE inputs

Constructions:

Name	U-value, W/(m2 K)	Thickness, m
Old north wall	0.1298	0.382
Internal walls 200 mm	0.1884	0.252
Concrete wall against ground 250mm	0.1588	0.423
Dragonvägen new external wall - Nort	0.1912	0.237
Dragonvägen Internal balcony wall	0.2053	0.231
Concrete floor 150mm	2.385	0.175
Dragonvägen old roof	0.1003	0.604
Dragonvägen new gable wall	0.4574	0.254
Canopy ETFE and glass walls	1.131	0.1
Dragonvägen new ground wall	0.5554	0.234
Dragonvägen old ground wall	2.835	0.305
Dragonvägen new ground wall to cano	0.5519	0.25
Dragonvägen Internal old north wall	0.2426	0.197
© Soil	1.493	1

Reference building renovation:

Name of zones	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2
(1)Basement	0	3.11	851.2	21	25	No centra	n.a.	n.a.	n.a.	0	2	7.3	0	0	0
(1)3 floor	11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)4 floor	13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)5 floor	16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)6 floor	19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)Penthouse	22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony ground floor	3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 3 floor	11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 4 floor	13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 5 floor	16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 6 floor	19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Ground floor	3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	49.5
(1)2 floor	8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)1 floor	5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(1)Balcony 2 floor	8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 1 floor	5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Basement	0	3.11	851.2	21	25	No centra	n.a.	n.a.	n.a.	0	2	7.3	0	0	0
(2)Ground floor	3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	49.5
(2)1 floor	5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)2 floor	8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)3 floor	11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)4 floor	13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)5 floor	16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)6 floor	19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)Balcony ground floor	3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 1 floor	5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 2 floor	8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 3 floor	11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 4 floor	13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 5 floor	16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 6 floor	19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Penthouse	22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
Total/m2									0.4	0.01711	1.71	6.242	0	0	43

Canopy 1 scenario:

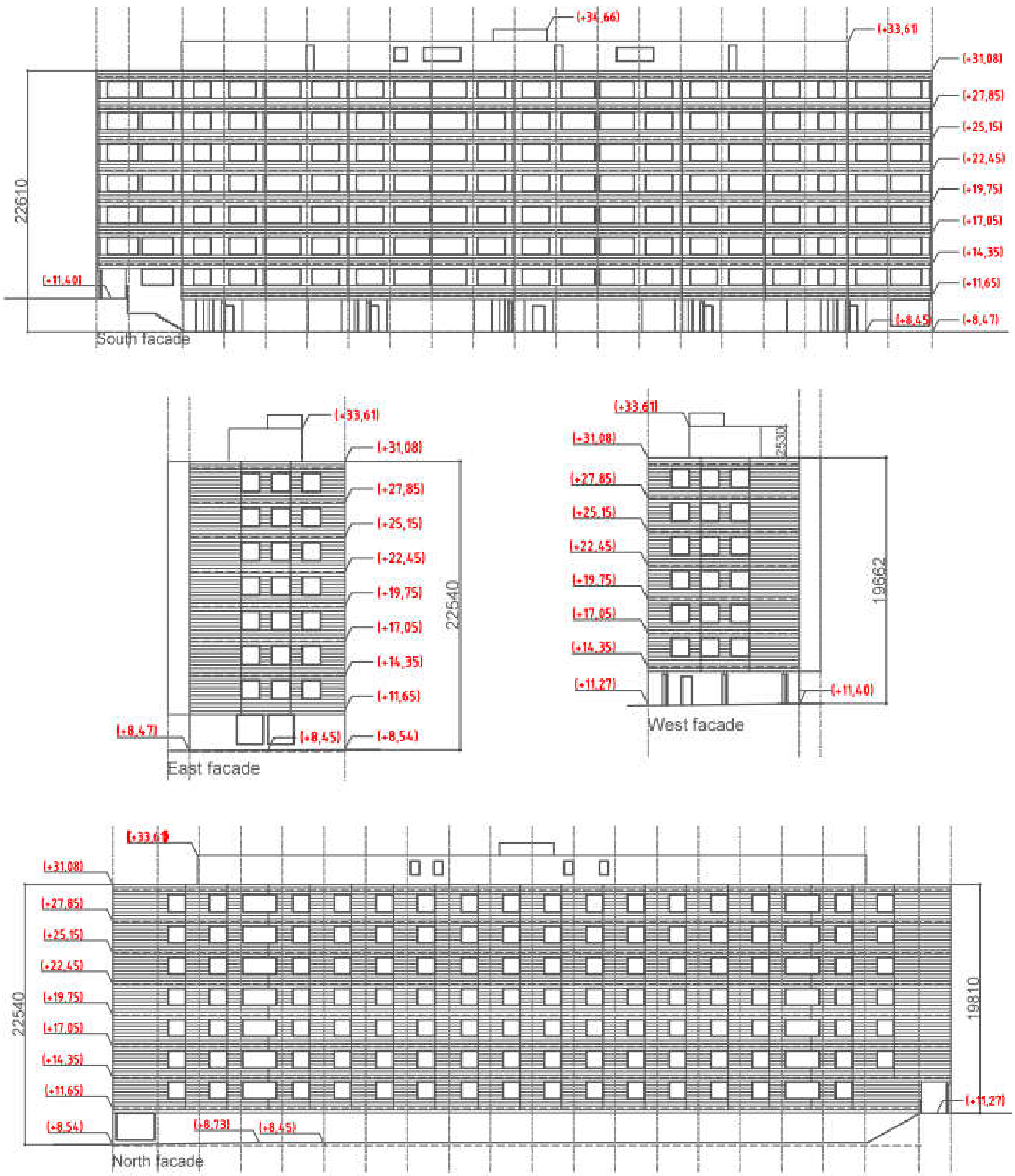
Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2
(1)Basement		0	3.11	851.2	21	25	No centra	n.a.	n.a.	n.a.	0	2	7.3	0	0	0
(1)3 floor		11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)4 floor		13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)5 floor		16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)6 floor		19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)Penthouse		22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony ground floor		3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 3 floor		11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 4 floor		13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 5 floor		16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 6 floor		19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Ground floor		3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	6.75
Canopy		0	22.54	1939	21	25	No centra	n.a.	n.a.	n.a.	5.16E-04	0	0	0	0	3286.5
(1)2 floor		8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)1 floor		5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	13.5
(1)Balcony 2 floor		8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 1 floor		5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Basement		0	3.11	969.5	21	25	No centra	n.a.	n.a.	n.a.	0	1.756	6.409	0	0	0
(2)Ground floor		3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	49.5
(2)1 floor		5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)2 floor		8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)3 floor		11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)4 floor		13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)5 floor		16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)6 floor		19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	58.5
(2)Balcony ground floor		3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 1 floor		5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 2 floor		8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 3 floor		11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 4 floor		13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 5 floor		16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 6 floor		19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Penthouse		22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
Total/m2										0.4	0.01526	1.519	5.545	0	0	369.2

Canopy 2 scenario:

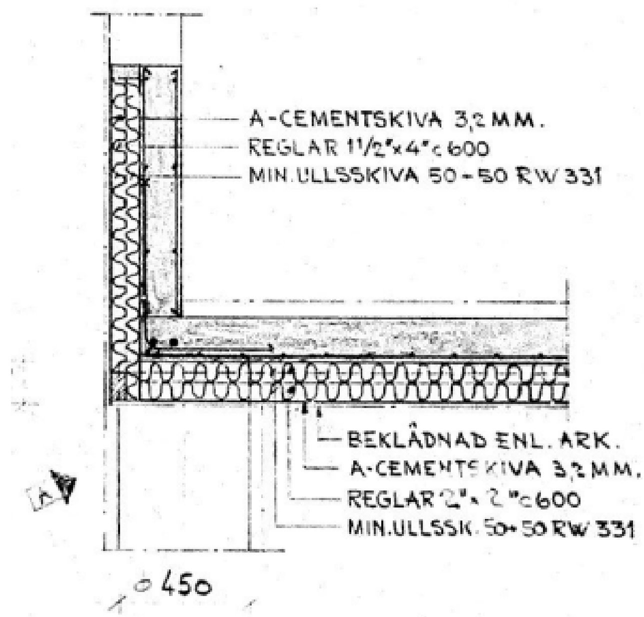
Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2
(1)Basement		0	3.11	851.2	21	25	No centra	n.a.	n.a.	n.a.	0	2	7.3	0	0	0
(1)3 floor		11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)4 floor		13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)5 floor		16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)6 floor		19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)Penthouse		22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony ground fl		3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 3 floor		11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 4 floor		13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 5 floor		16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 6 floor		19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Ground floor		3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	0
Canopy		0	22.54	2032	21	25	No centra	n.a.	n.a.	n.a.	4.92E-04	0	0	0	0	3440.4
(1)2 floor		8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)1 floor		5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	0
(1)Balcony 2 floor		8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(1)Balcony 1 floor		5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Basement		0	3.11	969.5	21	25	No centra	n.a.	n.a.	n.a.	0	1.756	6.409	0	0	0
(2)Ground floor		3.11	2.7	851.2	21	25	Return air	CAV		0.4	0.0235	2	7.3	0	0	42.75
(2)1 floor		5.81	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)2 floor		8.51	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)3 floor		11.21	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)4 floor		13.91	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)5 floor		16.61	2.7	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)6 floor		19.31	3.23	882.3	21	25	Return air	CAV		0.4	0.02267	2	7.3	0	0	45
(2)Balcony ground fl		3.11	2.7	118.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 1 floor		5.81	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 2 floor		8.52	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 3 floor		11.21	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 4 floor		13.91	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 5 floor		16.61	2.7	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Balcony 6 floor		19.31	3.23	122.6	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
(2)Penthouse		22.54	2.53	331.3	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	0
Passage South		3.11	2.7	35.46	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	5.1408
Passage North		3.11	2.7	35.46	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	5.7261
Canopy gable SW		3.11	19.43	27.7	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	262.8
Canopy gable NW		3.11	19.43	27.7	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	267.1
Canopy gable NE		0	22.54	27.7	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	316.19
Canopy gable SE		0	22.54	27.7	21	25	No centra	n.a.	n.a.	n.a.	0	0	0	0	0	303.02
Total/m2										0.4	0.01503	1.497	5.464	0	0	390.4

Appendix B: Original drawings of building

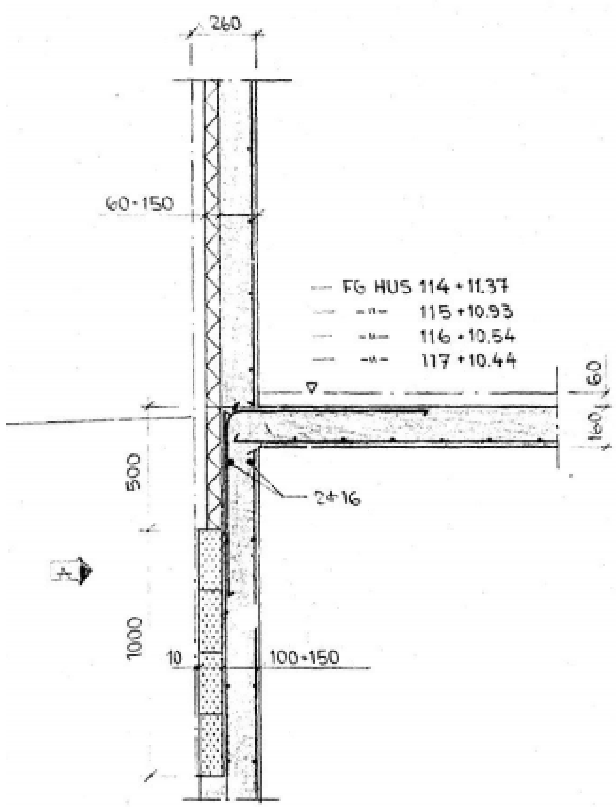
Facades:



Corner at gables:

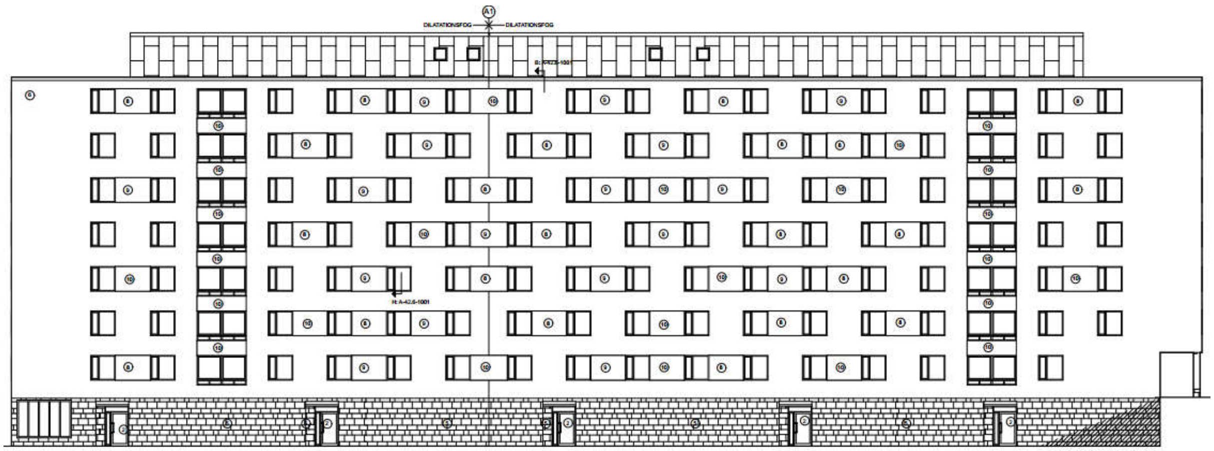


Gable walls:

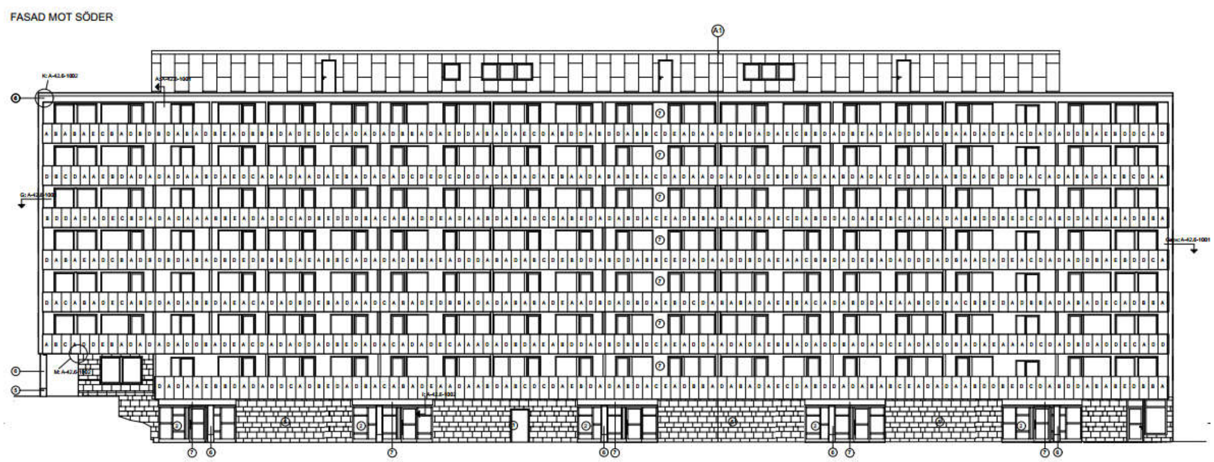


Appendix C: Renovation drawings of building

North facade:



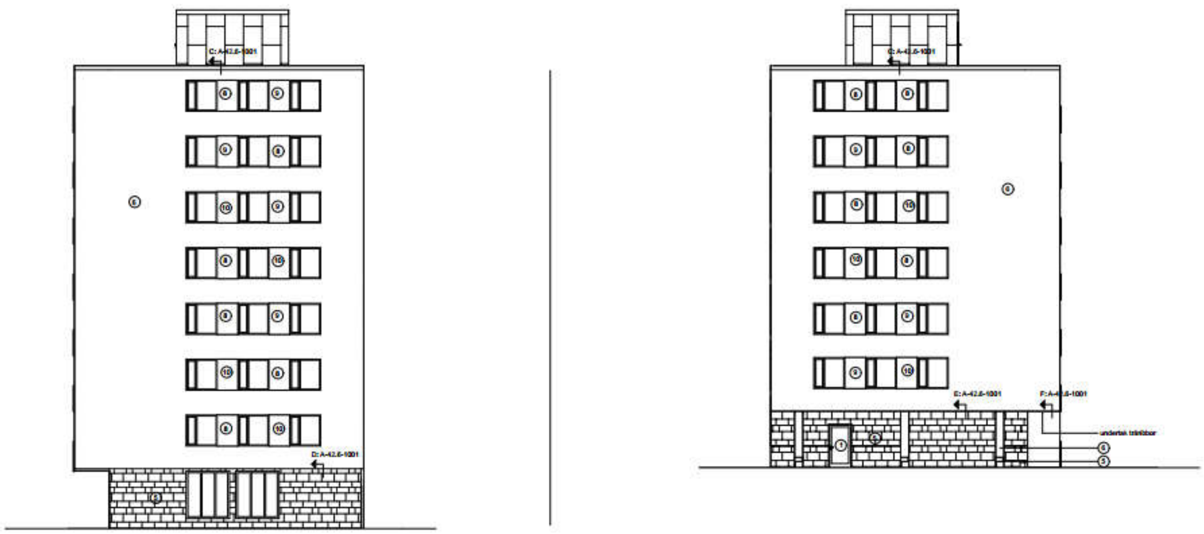
South facade:

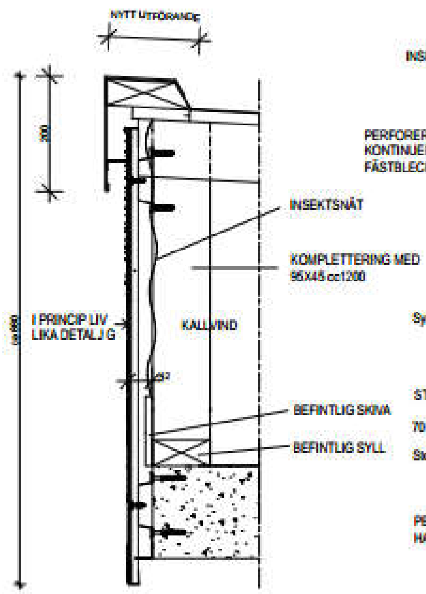


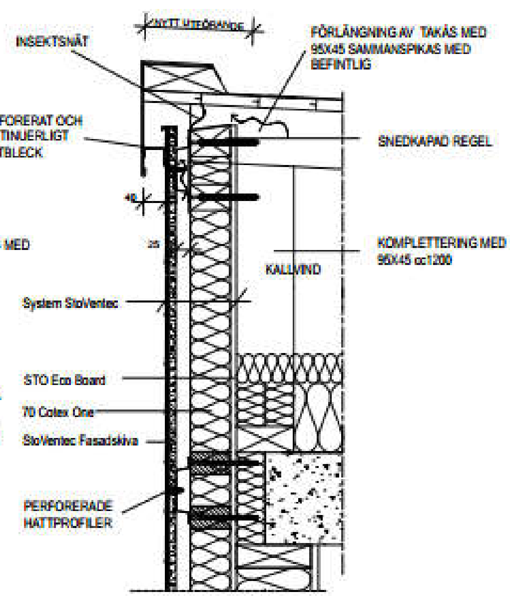
Gables:

FASAD MOT ÖSTER

FASAD MOT VÄSTER

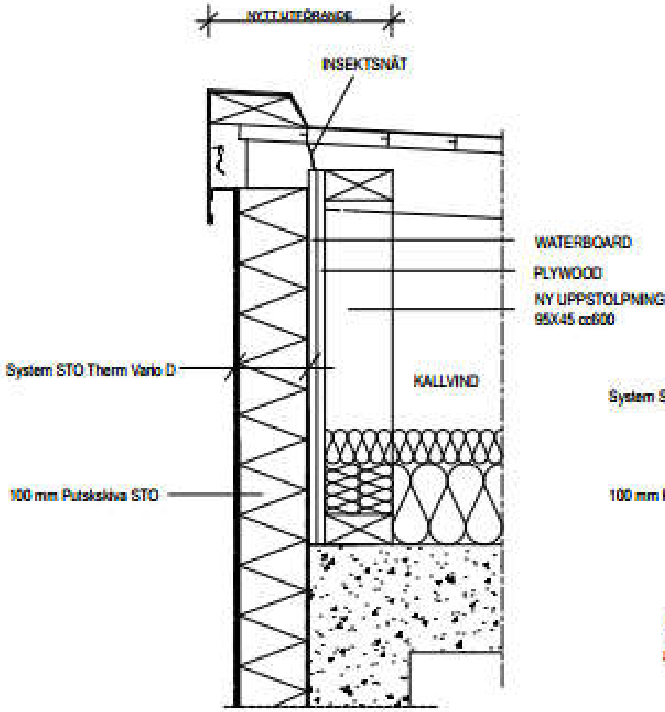




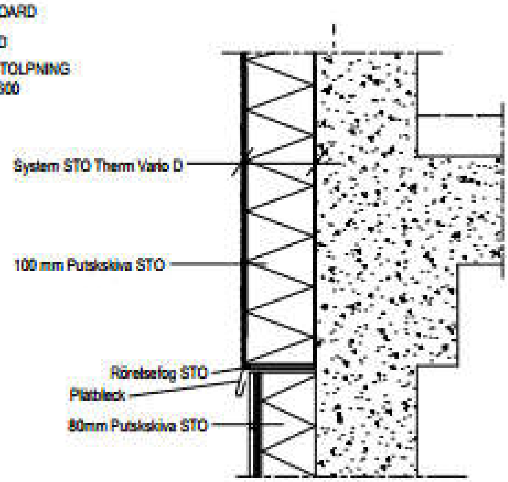


PRINCIPDETALJ A
VERIKALDETALJ BALKONG MOT KALLVIND

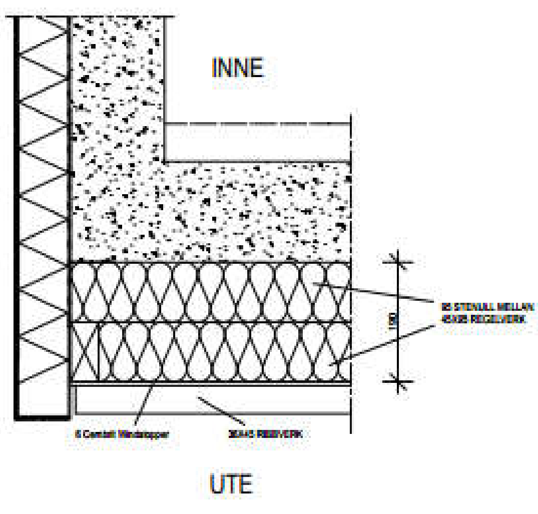
PRINCIPDETALJ B
VERTIKALDETALJ LÄGENHET MOT KALLVIND



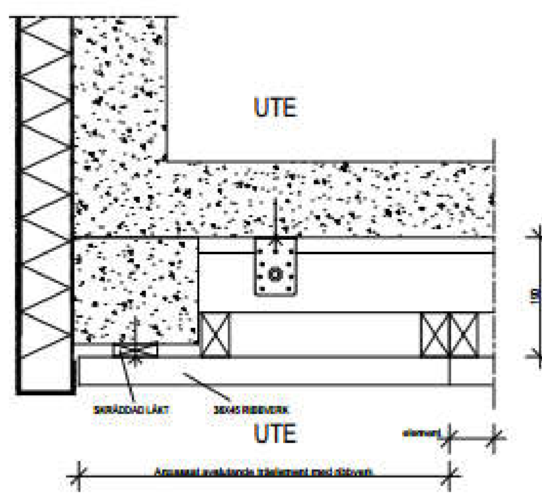
PRINCIPDETALJ C
VERTIKALDETALJ HUSGAVEL MOT KALLVIND



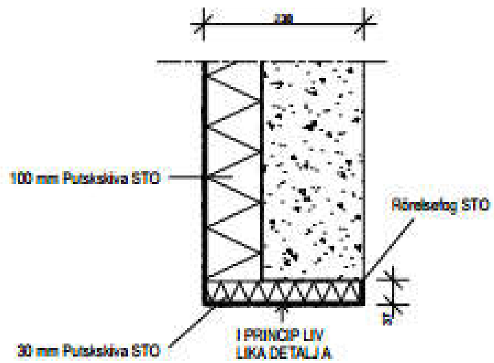
PRINCIPDETALJ D
VERTIKALDETALJ HUSGAVEL VID LOKAL



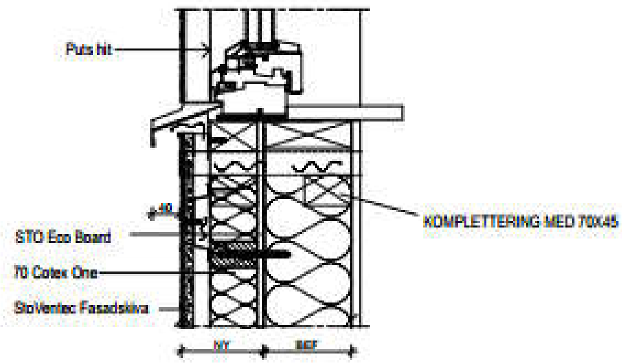
PRINCIPDETALJ E
VERTIKALDETALJ HUSGAVEL MED RIBBVERK VID LÄGENHET



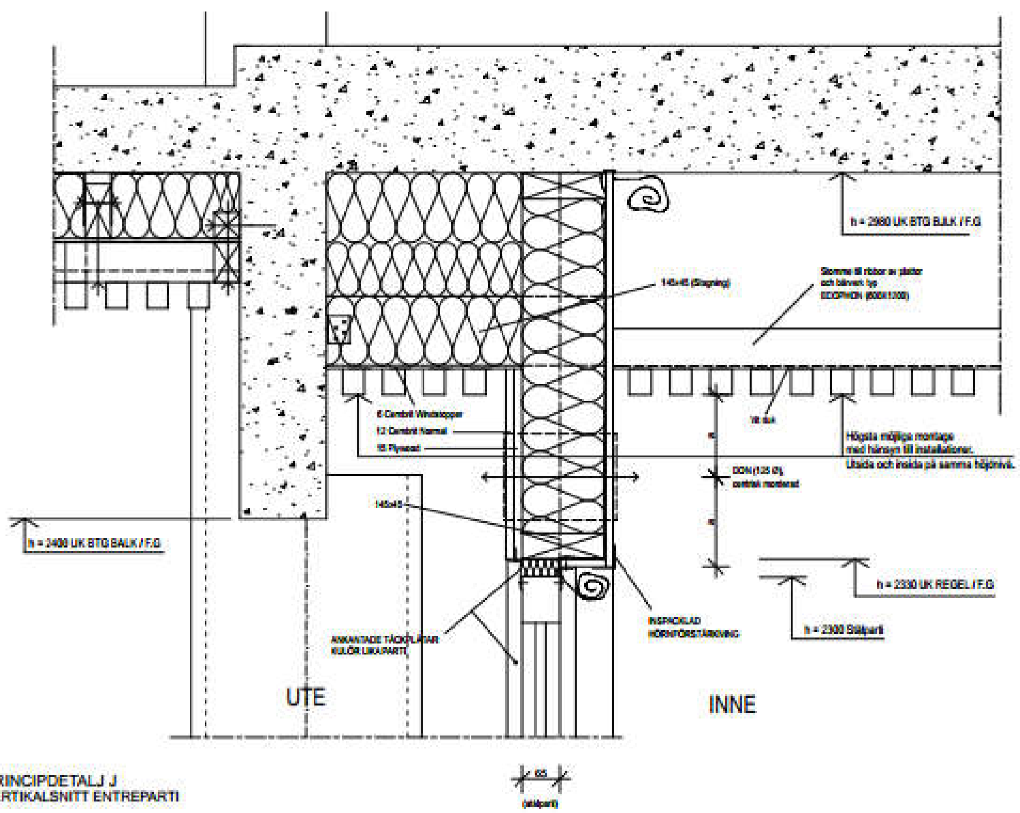
PRINCIPDETALJ F
VERTIKALDETALJ RIBBVERK VID BALKONG



PRINCIPDETALJ G
HORISONTALDETALJ BALKONG



PRINCIPDETALJ H
VERTIKALDETALJ HUSGAVEL VID LOKAL



PRINCIPDETALJ J
VERTIKALSNITT ENTREPARTI

Appendix D: Energy scenarios

The following tables is showing the distribution of energy sources in the Swedish future energy grid. The numbers are in %.

District heating - Forte

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Biofuels	47.6	47.2	46.8	46.4	46.0	45.6	45.2	44.8	44.3	43.9	43.5	43.1	42.7	42.3	41.9	41.5	41.0	40.6	40.2	39.8	39.4
Peat	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Waste	20.2	20.5	20.7	20.9	21.2	21.4	21.7	21.9	22.2	22.4	22.7	22.9	23.2	23.4	23.7	23.9	24.2	24.4	24.7	24.9	25.2
Waste heat	6.1	6.2	6.4	6.6	6.7	6.9	7.1	7.3	7.4	7.6	7.8	7.9	8.1	8.3	8.5	8.6	8.8	9.0	9.1	9.3	9.5
Oil	4.2	4.1	3.9	3.8	3.6	3.4	3.3	3.1	3.0	2.8	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.6	1.5	1.3	1.2
Coal	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6
Natural gas	8.6	8.5	8.4	8.3	8.2	8.2	8.1	8.0	7.9	7.8	7.7	7.6	7.6	7.5	7.4	7.3	7.2	7.1	7.0	7.0	6.9
Coke	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Heat pumps	8.6	8.7	8.9	9.1	9.2	9.4	9.5	9.7	9.8	10.0	10.1	10.3	10.5	10.6	10.8	10.9	11.1	11.2	11.4	11.6	11.7
Solar heating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

District heating - Forte

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
39.0	39.1	39.1	39.2	39.3	39.3	39.4	39.5	39.5	39.6	39.7	39.7	39.8	39.9	39.9	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
25.4	25.4	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6
9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
1.7	1.6	1.5	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Forte

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Nuclear power	41.5	41.6	41.8	41.9	42.0	42.1	42.3	42.4	42.5	42.7	42.8	42.9	43.0	43.2	43.3	43.4	43.6	43.7	43.8	44.0	44.1	44.2
Hydroelectric	42.2	41.9	41.7	41.4	41.1	40.8	40.5	40.3	40.0	39.7	39.4	39.1	38.8	38.6	38.3	38.0	37.7	37.4	37.2	36.9	36.6	36.3
CHP - Combined heat and power plant -	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.1
Onshore wind	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.9	7.9	7.9
Photovoltaic	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5
Wave power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Small scale bio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Forte

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
44.2	43.9	43.5	43.2	42.9	42.5	42.2	41.9	41.5	41.2	40.9	40.5	40.2	39.9	39.5	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2
36.3	36.5	36.8	37.0	37.2	37.5	37.7	37.9	38.2	38.4	38.6	38.9	39.1	39.3	39.5	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8	39.8
11.1	11.3	11.5	11.7	11.9	12.1	12.3	12.5	12.7	12.9	13.2	13.4	13.6	13.8	14.0	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
7.9	7.7	7.6	7.5	7.3	7.2	7.0	6.9	6.7	6.6	6.4	6.3	6.1	6.0	5.8	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

District heating - Legato

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Biofuels	47.6	47.4	47.2	47.0	46.8	46.6	46.4	46.2	46.0	45.8	45.6	45.4	45.2	44.9	44.7	44.5	44.3	44.1	43.9	43.7	43.5
Peat	2.9	2.7	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.6	1.5	1.4	1.2	1.1	1.0	0.8	0.7	0.5	0.4	0.3	0.1
Waste	20.2	20.4	20.6	20.7	20.9	21.1	21.3	21.4	21.6	21.8	22.0	22.1	22.3	22.5	22.7	22.8	23.0	23.2	23.4	23.5	23.7
Waste heat	6.1	6.5	6.9	7.3	7.7	8.2	8.6	9.0	9.4	9.9	10.3	10.7	11.1	11.5	12.0	12.4	12.8	13.2	13.7	14.1	14.5
Oil	4.2	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
Coal	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas	8.6	8.2	7.8	7.4	7.0	6.5	6.1	5.7	5.3	4.9	4.5	4.1	3.7	3.3	2.9	2.5	2.0	1.6	1.2	0.8	0.4
Coke	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.4	0.3	0.2	0.2	0.1
Heat pumps	8.6	9.0	9.5	9.9	10.4	10.8	11.3	11.7	12.1	12.6	13.0	13.5	13.9	14.4	14.8	15.2	15.7	16.1	16.6	17.0	17.5
Solar heating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

District heating - Legato

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
43.3	42.9	42.5	42.0	41.6	41.2	40.8	40.4	40.0	39.6	39.1	38.7	38.3	37.9	37.5	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.9	24.3	24.7	25.1	25.6	26.0	26.4	26.8	27.2	27.7	28.1	28.5	28.9	29.3	29.8	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
14.9	14.9	14.9	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.9	17.9	17.9	17.9	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Legato

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Nuclear power	41.5	39.5	37.5	35.6	33.6	31.6	29.6	27.7	25.7	23.7	21.7	19.8	17.8	15.8	13.8	11.9	9.9	7.9	5.9	4.0	2.0
Hydroelectric	42.2	42.5	42.7	42.9	43.1	43.4	43.6	43.8	44.1	44.3	44.5	44.7	45.0	45.2	45.4	45.6	45.9	46.1	46.3	46.6	46.8
CHP - Combined heat and power plant	8.8	8.8	8.7	8.7	8.7	8.7	8.6	8.6	8.6	8.6	8.5	8.5	8.5	8.4	8.4	8.4	8.4	8.3	8.3	8.3	8.2
Onshore wind	7.5	8.9	10.3	11.7	13.2	14.6	16.0	17.4	18.8	20.3	21.7	23.1	24.5	25.9	27.4	28.8	30.2	31.6	33.1	34.5	35.9
Photovoltaic	0.0	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.6	3.9	4.3	4.6	5.0	5.3	5.7	6.0	6.4	6.8	7.1
Wave power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Small scale bio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Legato

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47.0	46.4	45.7	45.0	44.4	43.7	43.1	42.4	41.8	41.1	40.4	39.8	39.1	38.5	37.8	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2	37.2
8.2	8.1	7.9	7.8	7.6	7.5	7.4	7.2	7.1	6.9	6.8	6.6	6.5	6.4	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
37.3	38.0	38.6	39.3	40.0	40.6	41.3	42.0	42.6	43.3	44.0	44.6	45.3	46.0	46.6	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3	47.3
7.5	7.5	7.5	7.6	7.6	7.7	7.7	7.8	7.8	7.8	7.9	7.9	8.0	8.0	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
0.0	0.1	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

District heating - Espressivo

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Biofuels	47.6	47.2	46.7	46.3	45.8	45.4	44.9	44.5	44.0	43.6	43.1	42.7	42.2	41.7	41.3	40.8	40.4	39.9	39.5	39.0	38.6
Peat	2.9	2.8	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.2	2.2	2.2	2.1	2.1
Waste	20.2	20.2	20.2	20.2	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.5	20.5	20.5
Waste heat	6.1	6.5	6.8	7.2	7.6	8.0	8.4	8.8	9.2	9.6	10.0	10.4	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	13.9
Oil	4.2	4.0	3.8	3.6	3.4	3.3	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.4
Coal	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas	8.6	8.3	8.0	7.7	7.4	7.1	6.8	6.5	6.2	5.9	5.6	5.3	5.0	4.7	4.4	4.1	3.8	3.5	3.2	2.9	2.6
Coke	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0
Heat pumps	8.6	9.0	9.3	9.7	10.1	10.4	10.8	11.2	11.6	11.9	12.3	12.7	13.0	13.4	13.8	14.2	14.5	14.9	15.3	15.6	16.0
Solar heating	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9

District heating - Espressivo

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.1
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
14.3	14.3	14.3	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4

Electrical System - Espressivo

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Nuclear power	41.5	40.6	39.6	38.7	37.8	36.8	35.9	35.0	34.0	33.1	32.2	31.2	30.3	29.4	28.5	27.5	26.6	25.7	24.7	23.8	22.9
Hydroelectric	42.2	42.1	41.9	41.7	41.6	41.4	41.2	41.1	40.9	40.7	40.6	40.4	40.2	40.1	39.9	39.7	39.5	39.4	39.2	39.0	38.9
CHP - Combined heat and power plant	8.8	8.9	9.0	9.0	9.1	9.2	9.2	9.3	9.4	9.5	9.5	9.6	9.7	9.7	9.8	9.9	10.0	10.0	10.1	10.2	10.3
Onshore wind	7.5	7.7	8.0	8.2	8.5	8.8	9.0	9.3	9.5	9.8	10.1	10.3	10.6	10.8	11.1	11.4	11.6	11.9	12.1	12.4	12.6
Photovoltaic	0.0	0.8	1.5	2.3	3.1	3.8	4.6	5.4	6.1	6.9	7.7	8.4	9.2	10.0	10.8	11.5	12.3	13.1	13.8	14.6	15.4
Wave power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Small scale bio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Espressivo

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
21.9	20.6	19.3	18.0	16.6	15.3	14.0	12.7	11.3	10.0	8.7	7.4	6.0	4.7	3.4	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
38.7	38.9	39.1	39.2	39.4	39.6	39.8	40.0	40.1	40.3	40.5	40.7	40.8	41.0	41.2	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4
10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.4	11.5	11.6	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
12.9	13.2	13.5	13.8	14.1	14.3	14.6	14.9	15.2	15.5	15.8	16.1	16.4	16.7	17.0	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2
16.1	16.4	16.7	17.0	17.3	17.6	18.0	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.5	0.9	1.4	1.8	2.3	2.8	3.2	3.7	4.1	4.6	5.1	5.5	6.0	6.4	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9

District heating - Vivace

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Biofuels	47.6	46.9	46.2	45.4	44.7	44.0	43.3	42.5	41.8	41.1	40.3	39.6	38.9	38.1	37.4	36.7	35.9	35.2	34.5	33.8	33.0
Peat	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
Waste	20.2	20.9	21.6	22.3	23.1	23.8	24.5	25.2	25.9	26.6	27.4	28.1	28.8	29.5	30.2	30.9	31.6	32.4	33.1	33.8	34.5
Waste heat	6.1	6.3	6.6	6.9	7.1	7.4	7.7	8.0	8.2	8.5	8.8	9.0	9.3	9.6	9.8	10.1	10.4	10.7	10.9	11.2	11.5
Oil	4.2	4.0	3.8	3.6	3.4	3.3	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.8	0.6	0.4
Coal	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas	8.6	8.2	7.8	7.4	7.0	6.5	6.1	5.7	5.3	4.9	4.5	4.1	3.7	3.3	2.9	2.5	2.0	1.6	1.2	0.8	0.4
Coke	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.4	0.3	0.2	0.2	0.1
Heat pumps	8.6	9.1	9.6	10.2	10.7	11.2	11.7	12.2	12.8	13.3	13.8	14.3	14.9	15.4	15.9	16.4	17.0	17.5	18.0	18.5	19.0
Solar heating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

District heating - Vivace

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
32.3	32.5	32.7	32.9	33.2	33.4	33.6	33.8	34.0	34.3	34.5	34.7	34.9	35.1	35.3	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6
1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.5	0.5	0.4	0.3	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35.2	35.7	36.3	36.8	37.3	37.8	38.3	38.8	39.4	39.9	40.4	40.9	41.4	41.9	42.4	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
11.7	11.9	12.1	12.3	12.4	12.6	12.8	12.9	13.1	13.3	13.5	13.6	13.8	14.0	14.1	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.6	18.7	17.9	17.1	16.3	15.4	14.6	13.8	13.0	12.1	11.3	10.5	9.6	8.8	8.0	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Vivace

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Nuclear power	41.5	40.3	39.1	38.0	36.8	35.6	34.4	33.3	32.1	30.9	29.7	28.5	27.4	26.2	25.0	23.8	22.7	21.5	20.3	19.1	18.0
Hydroelectric	42.2	42.2	42.2	42.2	42.2	42.2	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.0	42.0	42.0	42.0	42.0	42.0	42.0	41.9
CHP - Combined heat and power plant	8.8	9.1	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.7	12.0	12.3	12.6	12.9	13.3	13.6	13.9	14.2	14.5	14.8	15.2
Onshore wind	7.5	8.0	8.6	9.2	9.7	10.3	10.9	11.4	12.0	12.6	13.1	13.7	14.3	14.8	15.4	16.0	16.5	17.1	17.7	18.2	18.8
Photovoltaic	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1
Wave power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Small scale bio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Electrical System - Vivace

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064
16.8	15.7	14.5	13.4	12.3	11.2	10.1	8.9	7.8	6.7	5.6	4.5	3.4	2.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41.9	41.7	41.5	41.3	41.1	40.8	40.6	40.4	40.2	40.0	39.7	39.5	39.3	39.1	38.9	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
15.5	15.8	16.1	16.4	16.7	17.0	17.2	17.5	17.8	18.1	18.4	18.7	19.0	19.3	19.6	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9
19.4	20.0	20.6	21.2	21.8	22.4	23.0	23.6	24.2	24.8	25.4	26.0	26.6	27.2	27.8	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4
6.5	6.9	7.3	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9	11.3	11.7	12.1	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix E: Inventory flows

Canopy scenario 1:

Material	Process	Parameter	Unit	2020	2045	2070
ETFE	polyvinylfluoride, film production - US	PRO_ETFE	kg	2594.8	2594.8	
	treatment of waste polyvinylfluoride, municipal incineration - CH	EoL_ETFE	kg		-2594.8	-2594.8
	Dynamic	AVO_ETFE	kWh		-57656.6	-57656.6
Aluminium profiles	aluminium alloy production, AlMg3 - RER	PRO_Aluminium	kg	11641.9		
	treatment of waste reinforcement steel, recycling - CH	EoL_Aluminium_Recovery	kg			-10477.7
	treatment of waste aluminium, sanitary landfill - CH	EoL_Aluminium_Landfill	kg			-1164.2
	aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg			-10477.7
Silicone sealing	silicone product production - RER	PRO_Silicone	kg	613.9	613.9	
	treatment of waste rubber, unspecified, municipal incineration - CH	EoL_Silicone	kg		-613.9	-613.9
	Dynamic	AVO_Silicone	kWh		-13642.0	-13642.0
Glass	glazing production, double, U<1.1 W/m2K - RER	PRO_Glazing	m2	297.1	297.1	
	Treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	EoL_Glazing	m2		-297.1	-297.1
	window frame production, aluminium, U=1.6 W/m2K - RER	PRO_AluFrame	m2	15.6	15.6	
	treatment of waste reinforcement steel, recycling - CH	EoL_AluFrame_Recovery	kg		-886.5	-886.5
	treatment of waste aluminium, sanitary landfill - CH	EoL_AluFrame_Landfill	kg		-98.5	-98.5
	aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg		-886.5	-886.5
Timber	sawnwood production, softwood, kiln dried, planed - RER	PRO_Timber	m3	21.1		
	market for glued laminated timber, for indoor use - GLO	PRO_Glued_Timber	m3	14.4		
	treatment of waste wood, untreated, municipal incineration - CH	EoL_Timber	kg			-15997.0
	Dynamic	AVO_Timber	kWh			-355452.4
Steel	steel production, converter, low-alloyed - RER	PRO_Steel	kg	3021.3		
	treatment of waste reinforcement steel, recycling - CH	EoL_Steel_Recovery	kg			-2719.1
	treatment of scrap steel, inert material landfill - CH	EoL_Steel_Landfill	kg			-302.1
	steel production, converter, low-alloyed - RER	AVO_Steel	kg			-2719.1
Pump	pump production, 40W - CH	PRO_Pump	Item(s)	5.0	5.0	
	treatment of waste reinforcement steel, recycling - CH	EoL_Pump_Recovery	kg		-6.8	-6.8
	treatment of scrap steel, inert material landfill - CH	EoL_Pump_Landfill	kg		-0.8	-0.8
	steel production, converter, low-alloyed - RER	AVO_Pump	kg		-6.8	-6.8

Canopy scenario 2:

Material	Process	Parameter	Unit	2020	2045	2070
ETFE	polyvinylfluoride, film production - US	PRO_ETFE	kg	3612.2	3612.2	
	treatment of waste polyvinylfluoride, municipal incineration - CH	EoL_ETFE	kg		-3612.2	-3612.2
	Dynamic	AVO_ETFE	kWh		-80262.0	-80262.0
Aluminium profiles	aluminium alloy production, AlMg3 - RER	PRO_Aluminium	kg	16206.3		
	treatment of waste reinforcement steel, recycling - CH	EoL_Aluminium_Recovery	kg			-14585.7
	treatment of waste aluminium, sanitary landfill - CH	EoL_Aluminium_Landfill	kg			-1620.6
	aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg			-14585.7
Silicone sealing	silicone product production - RER	PRO_Silicone	kg	854.7	854.7	
	treatment of waste rubber, unspecified, municipal incineration - CH	EoL_Silicone	kg		-854.7	-854.7
	Dynamic	AVO_Silicone	kWh		-18990.6	-18990.6
Glass	glazing production, double, U<1.1 W/m2K - RER	PRO_Glazing	m2	653.5	653.5	
	Treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	EoL_Glazing	m2		-653.5	-653.5
	window frame production, aluminium, U=1.6 W/m2K - RER	PRO_AluFrame	m2	34.4	34.4	
	treatment of waste reinforcement steel, recycling - CH	EoL_AluFrame_Recovery	kg		-1950.2	-1950.2
	treatment of waste aluminium, sanitary landfill - CH	EoL_AluFrame_Landfill	kg		-216.7	-216.7
	aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg		-1950.2	-1950.2
Timber	sawnwood production, softwood, kiln dried, planed - RER	PRO_Timber	m3	46.5		
	market for glued laminated timber, for indoor use - GLO	PRO_Glued_Timber	m3	14.4		
	treatment of waste wood, untreated, municipal incineration - CH	EoL_Timber	kg			-27415.8
	Dynamic	AVO_Timber	kWh			-609178.7
Steel	steel production, converter, low-alloyed - RER	PRO_Steel	kg	6646.3		
	treatment of waste reinforcement steel, recycling - CH	EoL_Steel_Recovery	kg			-5981.7
	treatment of scrap steel, inert material landfill - CH	EoL_Steel_Landfill	kg			-664.6
	steel production, converter, low-alloyed - RER	AVO_Steel	kg			-5981.7
Pump	pump production, 40W - CH	PRO_Pump	Item(s)	7.0	7.0	
	treatment of waste reinforcement steel, recycling - CH	EoL_Pump_Recovery	kg		-9.5	-9.5
	treatment of scrap steel, inert material landfill - CH	EoL_Pump_Landfill	kg		-1.1	-1.1
	steel production, converter, low-alloyed - RER	AVO_Pump	kg		-9.5	-9.5

Avoided building materials:

Building part	Material	Process	Parameter	Unit	2020	2045	2070
Facade ground level north and south	XPS insulation board	polystyrene production, extruded, CO2 blown - RER	PRO_XPS	kg	1502.8		
		treatment of waste expanded polystyrene, municipal incineration - CH	EoL_XPS	kg			-1502.8
		Dynamic	AVO_XPS	kWh			-33392.2
	Mortar	cement mortar production - CH	Pro_Mortar	kg	2745.5		
		treatment of waste cement in concrete and mortar, collection for final disposal - CH	EoL_Mortar_Collect	kg			-2745.5
		treatment of waste cement, hydrated, residual material landfill - CH	EoL_Mortar_Landfill	kg			-2745.5
	Granite tiles	natural stone plate production, polished - CH	PRO_Granite	kg	11271.0		
		rock crushing - RER	EoL_Granite_Crushing	kg			-11271.0
		process-specific burdens production, inert material landfill - CH	EoL_Granite_Landfill	kg			-11271.0
Facade ground level gables	XPS insulation board	polystyrene production, extruded, CO2 blown - RER	PRO_XPS	kg	579.3		
		treatment of waste expanded polystyrene, municipal incineration - CH	EoL_XPS	kg			-579.3
		Dynamic	AVO_XPS	kWh			-12871.6
	Mortar	cement mortar production - CH	Pro_Mortar	kg	1058.3		
		treatment of waste cement in concrete and mortar, collection for final disposal - CH	EoL_Mortar_Collect	kg			-1058.3
		treatment of waste cement, hydrated, residual material landfill - CH	EoL_Mortar_Landfill	kg			-1058.3
	Granite tiles	natural stone plate production, polished - CH	PRO_Granite	kg	4344.6		
		rock crushing - RER	EoL_Granite_Crushing	kg			-4344.6
		process-specific burdens production, inert material landfill - CH	EoL_Granite_Landfill	kg			-4344.6
Facade north	stone mineral wool	rock wool production, packed - CH	PRO_MineralWool	kg	6208.2		
		treatment of waste mineral wool, inert material landfill - CH	EoL_MineralWool	kg			-6208.2
	Alu profiles	aluminium alloy production, AlMg3 - RER	PRO_Aluminium	kg	310.4		
		treatment of waste reinforcement steel, recycling - CH	EoL_Aluminium_Recovery	kg			-279.4
		treatment of waste aluminium, sanitary landfill - CH	EoL_Aluminium_Landfill	kg			-31.0
		aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg			-279.4

Building part	Material	Process	Parameter	Unit	2020	2045	2070
Facade gables	EPS insulation board	polystyrene production, expandable - RER	PRO_EPS	kg	3595.0		
		treatment of waste expanded polystyrene, municipal incineration - CH	EoL_EPS	kg			-3595.0
		Dynamic	AVO_EPS	kWh			-79880.9
Balcony at south facade	Laminated glass	flat glass production, coated - RER	PRO_Glass	kg	13140		
		treatment of waste glass, inert material landfill - CH	EoL_Glass	kg			-13140
Windows north	Window frame, alu	window frame production, aluminium, U=1.6 W/m2K - RER	PRO_AluFrame	m2	31.3	31.3	
		treatment of waste reinforcement steel, recycling - CH	EoL_AluFrame_Recovery	kg		-1773.3	-1773.3
		treatment of waste aluminium, sanitary landfill - CH	EoL_AluFrame_Landfill	kg		-197.0	-197.0
		aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg		-1773.3	-1773.3
	Glass	glazing production, triple, U<0.5 W/m2K - RER	PRO_Glass	m2	281.5	281.5	
		treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	EoL_Glass	m2		-281.5	-281.5
Windows gables	Window frame, alu	window frame production, aluminium, U=1.6 W/m2K - RER	PRO_AluFrame	m2	17.6	17.6	
		treatment of waste reinforcement steel, recycling - CH	EoL_AluFrame_Recovery	kg		-995.1	-995.1
		treatment of waste aluminium, sanitary landfill - CH	EoL_AluFrame_Landfill	kg		-110.6	-110.6
		aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg		-995.1	-995.1
	Glass	glazing production, triple, U<0.5 W/m2K - RER	PRO_Glass	m2	158.0	158.0	
		treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	EoL_Glass	m2		-158.0	-158.0
Windows south	Window frame, alu	window frame production, aluminium, U=1.6 W/m2K - RER	PRO_AluFrame	m2	61.8	61.8	
		treatment of waste reinforcement steel, recycling - CH	EoL_AluFrame_Recovery	kg		-3505.2	-3505.2
		treatment of waste aluminium, sanitary landfill - CH	EoL_AluFrame_Landfill	kg		-389.5	-389.5
		aluminium alloy production, AlMg3 - RER	AVO_Aluminium	kg		-3505.2	-3505.2
	Glass	glazing production, triple, U<0.5 W/m2K - RER	PRO_Glass	m2	556.4	556.4	
		treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	EoL_Glass	m2		-556.4	-556.4

Appendix F: End of life flows

	EoL flow	EoL dataset(s)		Next product system - Avoided process
		Share of mass	Dataset	
Expanded Polystyrene	1	100%	treatment of waste expanded polystyrene, municipal incineration - CH	Dynamic
Steel	2	90%	treatment of waste reinforcement steel, recycling - CH	steel production, converter, low-alloyed - RER
		10%	treatment of waste reinforcement steel, collection for final disposal - CH	-
Polystyrene	3	100%	treatment of waste polystyrene, municipal incineration - CH	Dynamic
Cement and mortar	4	100%	treatment of waste cement in concrete and mortar, collection for final disposal - CH	-
		100%	treatment of waste cement, hydrated, residual material landfill - CH	-
Timber	5	100%	heat production, untreated waste wood, at furnace 1000-5000 kW, state-of-the-art 2014 - CH	Dynamic
Glazing	6	100%	treatment of used triple glazing, U<0.5W/m2K, collection for final disposal - CH	flat glass production, uncoated - RER
Aluminium	7	90%	treatment of waste reinforcement steel, recycling - CH	aluminium alloy production, AlMg3 - RER
		10%	treatment of waste aluminium, sanitary landfill - CH	-
Tiles	8	100%	rock crushing - RER	-
		100%	process-specific burdens production, inert material landfill - CH	-
Laminated glass	9	100%	treatment of waste glass sheet, collection for final disposal - CH	flat glass production, uncoated - RER
Mineral wool	10	100%	treatment of waste mineral wool, inert material landfill - CH	-
ETFE	11	100%	treatment of waste polyvinylfluoride, municipal incineration - CH	Dynamic
Silicone sealing	12	100%	treatment of waste rubber, unspecified, municipal incineration - CH	Dynamic

Appendix G: Canopy 1 impact results

Climate Change - Canopy scenario 1				
	2020	2045	2070	
ETFE - Standard	54089.7	56789.3	2699.6	kg CO2 eq
ETFE - Forte	54089.7	55752.8	1766.8	kg CO2 eq
ETFE - Legato	54089.7	57704.4	3561.6	kg CO2 eq
ETFE - Espressivo	54089.7	56291.1	2204.6	kg CO2 eq
ETFE - Vivace	54089.7	57548.9	3676.8	kg CO2 eq
Silicone sealing - Standard	1994.8	3208.5	1213.7	kg CO2 eq
Silicone sealing - Forte	1994.8	2963.2	993.0	kg CO2 eq
Silicone sealing - Legato	1994.8	3425.0	1417.7	kg CO2 eq
Silicone sealing - Espressivo	1994.8	3090.6	1096.6	kg CO2 eq
Silicone sealing - Vivace	1994.8	3388.2	1444.9	kg CO2 eq
Aluminum profiles	75461.6	0.0	-67271.9	kg CO2 eq
Glass	10580.5	11702.3	1121.8	kg CO2 eq
Timber - Standard	4476.7	0.0	-18475.2	kg CO2 eq
Timber - Forte	4476.7	0.0	-24225.9	kg CO2 eq
Timber - Legato	4476.7	0.0	-13161.0	kg CO2 eq
Timber - Espressivo	4476.7	0.0	-21526.4	kg CO2 eq
Timber - Vivace	4476.7	0.0	-12450.6	kg CO2 eq
Pump	43.0	26.0	-16.9	kg CO2 eq
Steel	7710.3	0.0	-6776.9	kg CO2 eq
Aggregated				
	2020	2045	2070	
Standard	154357	71726	-87506	kg CO2 eq
Forte	154357	70444	-94410	kg CO2 eq
Legato	154357	72858	-81126	kg CO2 eq
Espressivo	154357	71110	-91169	kg CO2 eq
Vivace	154357	72665	-80273	kg CO2 eq

Ozone depletion - Canopy scenario 1				
	2020	2045	2070	
ETFE - Standard	0.0051	0.0023	-0.0028	kg CFC-11 eq
ETFE - Forte	0.0051	0.0017	-0.0034	kg CFC-11 eq
ETFE - Legato	0.0051	0.0006	-0.0045	kg CFC-11 eq
ETFE - Espressivo	0.0051	0.0011	-0.0040	kg CFC-11 eq
ETFE - Vivace	0.0051	0.0015	-0.0029	kg CFC-11 eq
Silicone sealing - Standard	0.0018	0.0011	-0.0007	kg CFC-11 eq
Silicone sealing - Forte	0.0018	0.0009	-0.0008	kg CFC-11 eq
Silicone sealing - Legato	0.0018	0.0007	-0.0011	kg CFC-11 eq
Silicone sealing - Espressivo	0.0018	0.0008	-0.0010	kg CFC-11 eq
Silicone sealing - Vivace	0.0018	0.0009	-0.0007	kg CFC-11 eq
Aluminum profiles	0.0209	0.0000	-0.0187	kg CFC-11 eq
Glass	0.0013	0.0015	0.0002	kg CFC-11 eq
Timber - Standard	0.0007	0.0000	-0.0178	kg CFC-11 eq
Timber - Forte	0.0007	0.0000	-0.0215	kg CFC-11 eq
Timber - Legato	0.0007	0.0000	-0.0283	kg CFC-11 eq
Timber - Espressivo	0.0007	0.0000	-0.0254	kg CFC-11 eq
Timber - Vivace	0.0007	0.0000	-0.0188	kg CFC-11 eq
Pump	0.0000	0.0000	0.0000	kg CFC-11 eq
Steel	0.0003	0.0000	-0.0003	kg CFC-11 eq
Aggregated				
	2020	2045	2070	
Standard	0.030	0.005	-0.040	kg CFC-11 eq
Forte	0.030	0.004	-0.044	kg CFC-11 eq
Legato	0.030	0.003	-0.053	kg CFC-11 eq
Espressivo	0.030	0.003	-0.049	kg CFC-11 eq
Vivace	0.030	0.004	-0.041	kg CFC-11 eq

Photochemical oxidant formation - Canopy scenario 1				
	2020	2045	2070	
ETFE - Standard	187.24	176.56	-10.67	kg NMVOC
ETFE - Forte	187.24	170.83	-16.07	kg NMVOC
ETFE - Legato	187.24	178.83	-8.42	kg NMVOC
ETFE - Espressivo	187.24	172.70	-14.54	kg NMVOC
ETFE - Vivace	187.24	177.93	-9.07	kg NMVOC
Silicone sealing - Standard	6.10	3.41	-2.69	kg NMVOC
Silicone sealing - Forte	6.10	2.05	-3.97	kg NMVOC
Silicone sealing - Legato	6.10	3.95	-2.16	kg NMVOC
Silicone sealing - Espressivo	6.10	2.50	-3.61	kg NMVOC
Silicone sealing - Vivace	6.10	3.73	-2.31	kg NMVOC
Aluminum profiles	413.91	0.00	-363.96	kg NMVOC
Glass	48.04	50.56	2.52	kg NMVOC
Timber - Standard	41.24	0.00	-71.76	kg NMVOC
Timber - Forte	41.24	0.00	-105.05	kg NMVOC
Timber - Legato	41.24	0.00	-57.84	kg NMVOC
Timber - Espressivo	41.24	0.00	-95.57	kg NMVOC
Timber - Vivace	41.24	0.00	-61.88	kg NMVOC
Pump	0.23	0.16	-0.07	kg NMVOC
Steel	31.97	0.00	-26.58	kg NMVOC
Aggregated				
	2020	2045	2070	
Standard	728.73	230.69	-473.21	kg NMVOC
Forte	728.73	223.60	-513.18	kg NMVOC
Legato	728.73	233.50	-456.50	kg NMVOC
Espressivo	728.73	225.91	-501.80	kg NMVOC
Vivace	728.73	232.38	-461.35	kg NMVOC

Terrestrial acidification - Canopy scenario 1				
	2020	2045	2070	
ETFE - Standard	321.19	302.86	-18.33	kg SO2 eq
ETFE - Forte	321.19	303.40	-17.43	kg SO2 eq
ETFE - Legato	321.19	309.93	-11.45	kg SO2 eq
ETFE - Espressivo	321.19	305.18	-16.01	kg SO2 eq
ETFE - Vivace	321.19	308.45	-12.57	kg SO2 eq
Silicone sealing - Standard	8.69	4.14	-4.55	kg SO2 eq
Silicone sealing - Forte	8.69	4.26	-4.34	kg SO2 eq
Silicone sealing - Legato	8.69	5.81	-2.93	kg SO2 eq
Silicone sealing - Espressivo	8.69	4.69	-4.01	kg SO2 eq
Silicone sealing - Vivace	8.69	5.46	-3.19	kg SO2 eq
Aluminum profiles	520.59	0.00	-463.48	kg SO2 eq
Glass	84.43	87.25	2.82	kg SO2 eq
Timber - Standard	29.30	0.00	-122.01	kg SO2 eq
Timber - Forte	29.30	0.00	-116.51	kg SO2 eq
Timber - Legato	29.30	0.00	-79.61	kg SO2 eq
Timber - Espressivo	29.30	0.00	-107.73	kg SO2 eq
Timber - Vivace	29.30	0.00	-86.55	kg SO2 eq
Pump	0.55	0.48	-0.07	kg SO2 eq
Steel	31.24	0.00	-26.83	kg SO2 eq
Aggregated				
	2020	2045	2070	
Standard	995.98	394.73	-632.45	kg SO2 eq
Forte	995.98	395.39	-625.85	kg SO2 eq
Legato	995.98	403.47	-581.55	kg SO2 eq
Espressivo	995.98	397.60	-615.30	kg SO2 eq
Vivace	995.98	401.64	-589.87	kg SO2 eq

Freshwater eutrophication - Canopy scenario 1				
	2020	2045	2070	
ETFE - Standard	15.45	14.63	-0.82	kg P eq
ETFE - Forte	15.45	12.38	-3.02	kg P eq
ETFE - Legato	15.45	14.65	-0.82	kg P eq
ETFE - Espressivo	15.45	12.89	-2.56	kg P eq
ETFE - Vivace	15.45	14.48	-0.67	kg P eq
Silicone sealing - Standard	0.55	0.34	-0.21	kg P eq
Silicone sealing - Forte	0.55	-0.20	-0.73	kg P eq
Silicone sealing - Legato	0.55	0.34	-0.21	kg P eq
Silicone sealing - Espressivo	0.55	-0.07	-0.62	kg P eq
Silicone sealing - Vivace	0.55	0.30	-0.17	kg P eq
Aluminum profiles	41.61	0.00	-37.42	kg P eq
Glass	2.45	2.63	0.17	kg P eq
Timber - Standard	1.56	0.00	-5.65	kg P eq
Timber - Forte	1.56	0.00	-19.21	kg P eq
Timber - Legato	1.56	0.00	-5.63	kg P eq
Timber - Espressivo	1.56	0.00	-16.32	kg P eq
Timber - Vivace	1.56	0.00	-4.70	kg P eq
Pump	0.11	0.09	-0.02	kg P eq
Steel	6.88	0.00	-6.19	kg P eq
Aggregated				
	2020	2045	2070	
Standard	68.61	17.68	-50.13	kg P eq
Forte	68.61	14.90	-66.42	kg P eq
Legato	68.61	17.71	-50.11	kg P eq
Espressivo	68.61	15.54	-62.95	kg P eq
Vivace	68.61	17.50	-48.99	kg P eq

Appendix H: Canopy 2 impact results

Climate Change - Canopy scenario 2				
	2020	2045	2070	
ETFE - Standard	75297.9	79056.0	3758.1	kg CO2 eq
ETFE - Forte	75297.9	77613.1	2459.6	kg CO2 eq
ETFE - Legato	75297.9	80329.9	4958.1	kg CO2 eq
ETFE - Espressivo	75297.9	78362.5	3069.1	kg CO2 eq
ETFE - Vivace	75297.9	80113.3	5118.5	kg CO2 eq
Silicone sealing - Standard	2777.2	4467.1	1689.9	kg CO2 eq
Silicone sealing - Forte	2777.2	4125.7	1382.6	kg CO2 eq
Silicone sealing - Legato	2777.2	4768.5	1973.8	kg CO2 eq
Silicone sealing - Espressivo	2777.2	4303.0	1526.9	kg CO2 eq
Silicone sealing - Vivace	2777.2	4717.3	2011.8	kg CO2 eq
Aluminum profiles	105048.0	0.0	-93647.3	kg CO2 eq
Glass	10580.5	11702.3	1121.8	kg CO2 eq
Timber - Standard	5809.7	0.0	-31663.0	kg CO2 eq
Timber - Forte	5809.7	0.0	-41518.7	kg CO2 eq
Timber - Legato	5809.7	0.0	-22555.5	kg CO2 eq
Timber - Espressivo	5809.7	0.0	-36892.1	kg CO2 eq
Timber - Vivace	5809.7	0.0	-21337.9	kg CO2 eq
Pump	60.2	36.5	-23.7	kg CO2 eq
Steel	16961.3	0.0	-14908.5	kg CO2 eq
Aggregated				
	2020	2045	2070	
Standard	216535	95262	-133673	kg CO2 eq
Forte	216535	93478	-145134	kg CO2 eq
Legato	216535	96837	-123081	kg CO2 eq
Espressivo	216535	94404	-139754	kg CO2 eq
Vivace	216535	96569	-121665	kg CO2 eq

Ozone depletion - Canopy scenario 2				
	2020	2045	2070	
ETFE - Standard	0.0071	0.0032	-0.0039	kg CFC-11 eq
ETFE - Forte	0.0071	0.0024	-0.0047	kg CFC-11 eq
ETFE - Legato	0.0071	0.0009	-0.0062	kg CFC-11 eq
ETFE - Espressivo	0.0071	0.0015	-0.0056	kg CFC-11 eq
ETFE - Vivace	0.0071	0.0021	-0.0041	kg CFC-11 eq
Silicone sealing - Standard	0.0025	0.0015	-0.0009	kg CFC-11 eq
Silicone sealing - Forte	0.0025	0.0013	-0.0011	kg CFC-11 eq
Silicone sealing - Legato	0.0025	0.0010	-0.0015	kg CFC-11 eq
Silicone sealing - Espressivo	0.0025	0.0011	-0.0013	kg CFC-11 eq
Silicone sealing - Vivace	0.0025	0.0012	-0.0010	kg CFC-11 eq
Aluminum profiles	0.0290	0.0000	-0.0260	kg CFC-11 eq
Glass	0.0013	0.0015	0.0002	kg CFC-11 eq
Timber - Standard	0.0010	0.0000	-0.0306	kg CFC-11 eq
Timber - Forte	0.0010	0.0000	-0.0368	kg CFC-11 eq
Timber - Legato	0.0010	0.0000	-0.0484	kg CFC-11 eq
Timber - Espressivo	0.0010	0.0000	-0.0435	kg CFC-11 eq
Timber - Vivace	0.0010	0.0000	-0.0323	kg CFC-11 eq
Pump	0.0000	0.0000	0.0000	kg CFC-11 eq
Steel	0.0008	0.0000	-0.0006	kg CFC-11 eq

Aggregated				
	2020	2045	2070	
Standard	0.0416	0.0062	-0.0618	kg CFC-11 eq
Forte	0.0416	0.0052	-0.0690	kg CFC-11 eq
Legato	0.0416	0.0034	-0.0825	kg CFC-11 eq
Espressivo	0.0416	0.0041	-0.0769	kg CFC-11 eq
Vivace	0.0416	0.0048	-0.0638	kg CFC-11 eq

Photochemical oxidant formation - Canopy scenario 2				
	2020	2045	2070	
ETFE - Standard	260.65	245.79	-14.86	kg NMVOC
ETFE - Forte	260.65	237.81	-22.38	kg NMVOC
ETFE - Legato	260.65	248.95	-11.72	kg NMVOC
ETFE - Espressivo	260.65	240.41	-20.24	kg NMVOC
ETFE - Vivace	260.65	247.69	-12.63	kg NMVOC
Silicone sealing - Standard	8.50	4.75	-3.75	kg NMVOC
Silicone sealing - Forte	8.50	2.86	-5.53	kg NMVOC
Silicone sealing - Legato	8.50	5.49	-3.00	kg NMVOC
Silicone sealing - Espressivo	8.50	3.48	-5.02	kg NMVOC
Silicone sealing - Vivace	8.50	5.20	-3.22	kg NMVOC
Aluminum profiles	576.19	0.00	-506.66	kg NMVOC
Glass	48.04	50.56	2.52	kg NMVOC
Timber - Standard	59.59	0.00	-122.98	kg NMVOC
Timber - Forte	59.59	0.00	-180.04	kg NMVOC
Timber - Legato	59.59	0.00	-99.13	kg NMVOC
Timber - Espressivo	59.59	0.00	-163.80	kg NMVOC
Timber - Vivace	59.59	0.00	-106.06	kg NMVOC
Pump	0.32	0.23	-0.09	kg NMVOC
Steel	70.33	0.00	-58.48	kg NMVOC
Aggregated				
	2020	2045	2070	
Standard	1023.61	301.33	-704.29	kg NMVOC
Forte	1023.61	291.45	-770.65	kg NMVOC
Legato	1023.61	305.23	-676.56	kg NMVOC
Espressivo	1023.61	294.67	-751.76	kg NMVOC
Vivace	1023.61	303.67	-684.61	kg NMVOC

Terrestrial acidification - Canopy scenario 2				
	2020	2045	2070	
ETFE - Standard	447.12	421.61	-25.51	kg SO2 eq
ETFE - Forte	447.12	422.36	-24.27	kg SO2 eq
ETFE - Legato	447.12	431.45	-15.94	kg SO2 eq
ETFE - Espressivo	447.12	424.83	-22.29	kg SO2 eq
ETFE - Vivace	447.12	429.39	-17.50	kg SO2 eq
Silicone sealing - Standard	12.10	5.76	-6.34	kg SO2 eq
Silicone sealing - Forte	12.10	5.94	-6.05	kg SO2 eq
Silicone sealing - Legato	12.10	8.09	-4.07	kg SO2 eq
Silicone sealing - Espressivo	12.10	6.52	-5.58	kg SO2 eq
Silicone sealing - Vivace	12.10	7.60	-4.44	kg SO2 eq
Aluminum profiles	724.69	0.00	-645.20	kg SO2 eq
Glass	84.43	87.25	2.82	kg SO2 eq
Timber - Standard	38.49	0.00	-209.10	kg SO2 eq
Timber - Forte	38.49	0.00	-199.68	kg SO2 eq
Timber - Legato	38.49	0.00	-136.45	kg SO2 eq
Timber - Espressivo	38.49	0.00	-184.63	kg SO2 eq
Timber - Vivace	38.49	0.00	-148.33	kg SO2 eq
Pump	0.77	0.68	-0.09	kg SO2 eq
Steel	68.72	0.00	-59.03	kg SO2 eq

Aggregated				
	2020	2045	2070	
Standard	1376.32	515.30	-942.45	kg SO2 eq
Forte	1376.32	516.22	-931.49	kg SO2 eq
Legato	1376.32	527.47	-857.96	kg SO2 eq
Espressivo	1376.32	519.29	-913.99	kg SO2 eq
Vivace	1376.32	524.92	-871.77	kg SO2 eq

Freshwater eutrophication - Canopy scenario 2				
	2020	2045	2070	
ETFE - Standard	21.509	20.362	-1.148	kg P eq
ETFE - Forte	21.509	17.234	-4.211	kg P eq
ETFE - Legato	21.509	20.389	-1.145	kg P eq
ETFE - Espressivo	21.509	17.951	-3.558	kg P eq
ETFE - Vivace	21.509	20.153	-0.934	kg P eq
Silicone sealing - Standard	0.760	0.468	-0.292	kg P eq
Silicone sealing - Forte	0.760	-0.272	-1.017	kg P eq
Silicone sealing - Legato	0.760	0.474	-0.292	kg P eq
Silicone sealing - Espressivo	0.760	-0.103	-0.863	kg P eq
Silicone sealing - Vivace	0.760	0.418	-0.242	kg P eq
Aluminum profiles	57.927	0.000	-52.094	kg P eq
Glass	2.453	2.626	0.173	kg P eq
Timber - Standard	1.933	0.000	-9.676	kg P eq
Timber - Forte	1.933	0.000	-32.923	kg P eq
Timber - Legato	1.933	0.000	-9.652	kg P eq
Timber - Espressivo	1.933	0.000	-27.973	kg P eq
Timber - Vivace	1.933	0.000	-8.051	kg P eq
Pump	0.154	0.133	-0.022	kg P eq
Steel	15.134	0.000	-13.607	kg P eq
Aggregated				
	2020	2045	2070	
Standard	99.87	23.59	-76.67	kg P eq
Forte	99.87	19.72	-103.70	kg P eq
Legato	99.87	23.62	-76.64	kg P eq
Espressivo	99.87	20.61	-97.94	kg P eq
Vivace	99.87	23.33	-74.78	kg P eq

Appendix I: Avoided building material impact results

Climate Change - Avoided renovation materials				
	2020	2045	2070	
Facade ground N & S - Standard	16223.9	0.0	3003.6	kg CO2 eq
Facade ground N & S - Forte	16223.9	0.0	2463.4	kg CO2 eq
Facade ground N & S - Legato	16223.9	0.0	3502.8	kg CO2 eq
Facade ground N & S - Espressivo	16223.9	0.0	2717.0	kg CO2 eq
Facade ground N & S - Vivace	16223.9	0.0	3569.6	kg CO2 eq
Facade ground gables - Standard	6253.9	0.0	1157.9	kg CO2 eq
Facade ground gables - Forte	6253.9	0.0	949.6	kg CO2 eq
Facade ground gables - Legato	6253.9	0.0	1350.3	kg CO2 eq
Facade ground gables - Espressivo	6253.9	0.0	1047.4	kg CO2 eq
Facade ground gables - Vivace	6253.9	0.0	1376.0	kg CO2 eq
Balcony at south facade	14459.8	0.0	71.4	kg CO2 eq
Facade north	11036.0	0.0	-1776.6	kg CO2 eq
Facade gables - Standard	12140.2	0.0	7128.1	kg CO2 eq
Facade gables - Forte	12140.2	0.0	5835.7	kg CO2 eq
Facade gables - Legato	12140.2	0.0	8322.3	kg CO2 eq
Facade gables - Espressivo	12140.2	0.0	6442.4	kg CO2 eq
Facade gables - Vivace	12140.2	0.0	8482.0	kg CO2 eq
Windows south	79690.1	59285.9	-20404.2	kg CO2 eq
Windows north	40343.0	30020.5	-10322.5	kg CO2 eq
Windows gables	22667.9	16875.5	-5792.4	kg CO2 eq
Aggregated				
	2020	2045	2070	
Standard	202815	106182	-26935	kg CO2 eq
Forte	202815	106182	-28976	kg CO2 eq
Legato	202815	106182	-25049	kg CO2 eq
Espressivo	202815	106182	-28018	kg CO2 eq
Vivace	202815	106182	-24797	kg CO2 eq

Ozone depletion - Avoided renovation materials				
	2020	2045	2070	
Facade ground N & S - Standard	0.0014	0.0000	-0.0017	kg CFC-11 eq
Facade ground N & S - Forte	0.0014	0.0000	-0.0020	kg CFC-11 eq
Facade ground N & S - Legato	0.0014	0.0000	-0.0026	kg CFC-11 eq
Facade ground N & S - Espressivo	0.0014	0.0000	-0.0024	kg CFC-11 eq
Facade ground N & S - Vivace	0.0014	0.0000	-0.0018	kg CFC-11 eq
Facade ground gables - Standard	0.0005	0.0000	-0.0006	kg CFC-11 eq
Facade ground gables - Forte	0.0005	0.0000	-0.0008	kg CFC-11 eq
Facade ground gables - Legato	0.0005	0.0000	-0.0010	kg CFC-11 eq
Facade ground gables - Espressivo	0.0005	0.0000	-0.0009	kg CFC-11 eq
Facade ground gables - Vivace	0.0005	0.0000	-0.0007	kg CFC-11 eq
Balcony at south facade	0.0013	0.0000	0.0000	kg CFC-11 eq
Facade north	0.0011	0.0000	-0.0005	kg CFC-11 eq
Facade gables - Standard	0.0002	0.0000	-0.0040	kg CFC-11 eq
Facade gables - Forte	0.0002	0.0000	-0.0048	kg CFC-11 eq
Facade gables - Legato	0.0002	0.0000	-0.0063	kg CFC-11 eq
Facade gables - Espressivo	0.0002	0.0000	-0.0057	kg CFC-11 eq
Facade gables - Vivace	0.0002	0.0000	-0.0042	kg CFC-11 eq
Windows south	0.0054	-0.0004	-0.0058	kg CFC-11 eq
Windows north	0.0028	-0.0002	-0.0030	kg CFC-11 eq
Windows gables	0.0015	-0.0001	-0.0017	kg CFC-11 eq
Aggregated				
	2020	2045	2070	
Standard	0.0142	-0.0007	-0.0172	kg CFC-11 eq
Forte	0.0142	-0.0007	-0.0185	kg CFC-11 eq
Legato	0.0142	-0.0007	-0.0209	kg CFC-11 eq
Espressivo	0.0142	-0.0007	-0.0199	kg CFC-11 eq
Vivance	0.0142	-0.0007	-0.0176	kg CFC-11 eq

Photochemical oxidant formation - Avoided renovation materials				
	2020	2045	2070	
Facade ground N & S - Standard	73.44	0.00	-6.48	kg NMVOC
Facade ground N & S - Forte	73.44	0.00	-9.61	kg NMVOC
Facade ground N & S - Legato	73.44	0.00	-5.17	kg NMVOC
Facade ground N & S - Espressivo	73.44	0.00	-8.72	kg NMVOC
Facade ground N & S - Vivace	73.44	0.00	-5.55	kg NMVOC
Facade ground gables - Standard	28.31	0.00	-2.50	kg NMVOC
Facade ground gables - Forte	28.31	0.00	-3.70	kg NMVOC
Facade ground gables - Legato	28.31	0.00	-1.99	kg NMVOC
Facade ground gables - Espressivo	28.31	0.00	-3.36	kg NMVOC
Facade ground gables - Vivace	28.31	0.00	-2.14	kg NMVOC
Balcony at south facade	71.53	0.00	0.74	kg NMVOC
Facade north	50.04	0.00	-9.58	kg NMVOC
Facade gables - Standard	40.31	0.00	-15.95	kg NMVOC
Facade gables - Forte	40.31	0.00	-23.44	kg NMVOC
Facade gables - Legato	40.31	0.00	-12.83	kg NMVOC
Facade gables - Espressivo	40.31	0.00	-21.31	kg NMVOC
Facade gables - Vivace	40.31	0.00	-13.73	kg NMVOC
Windows south	315.32	198.28	-117.04	kg NMVOC
Windows north	159.62	100.41	-59.21	kg NMVOC
Windows gables	89.68	56.46	-33.23	kg NMVOC

Aggregated				
	2020	2045	2070	
Standard	828.3	355.1	-243.2	kg NMVOC
Forte	828.3	355.1	-255.1	kg NMVOC
Legato	828.3	355.1	-238.3	kg NMVOC
Espressivo	828.3	355.1	-251.7	kg NMVOC
Vivace	828.3	355.1	-239.7	kg NMVOC

Terrestrial acidification - Avoided renovation materials				
	2020	2045	2070	
Facade ground N & S - Standard	82.08	0.00	-11.23	kg SO2 eq
Facade ground N & S - Forte	82.08	0.00	-10.71	kg SO2 eq
Facade ground N & S - Legato	82.08	0.00	-7.24	kg SO2 eq
Facade ground N & S - Espressivo	82.08	0.00	-9.88	kg SO2 eq
Facade ground N & S - Vivace	82.08	0.00	-7.89	kg SO2 eq
Facade ground gables - Standard	31.64	0.00	-4.33	kg SO2 eq
Facade ground gables - Forte	31.64	0.00	-4.13	kg SO2 eq
Facade ground gables - Legato	31.64	0.00	-2.79	kg SO2 eq
Facade ground gables - Espressivo	31.64	0.00	-3.81	kg SO2 eq
Facade ground gables - Vivace	31.64	0.00	-3.04	kg SO2 eq
Balcony at south facade	127.36	0.00	0.54	kg SO2 eq
Facade north	81.73	0.00	-12.24	kg SO2 eq
Facade gables - Standard	35.23	0.00	-27.26	kg SO2 eq
Facade gables - Forte	35.23	0.00	-26.03	kg SO2 eq
Facade gables - Legato	35.23	0.00	-17.74	kg SO2 eq
Facade gables - Espressivo	35.23	0.00	-24.05	kg SO2 eq
Facade gables - Vivace	35.23	0.00	-19.29	kg SO2 eq
Windows south	596.31	446.54	-149.77	kg SO2 eq
Windows north	301.88	226.11	-75.77	kg SO2 eq
Windows gables	169.62	127.10	-42.52	kg SO2 eq
Aggregated				
	2020	2045	2070	
Standard	1425.8	799.7	-322.6	kg SO2 eq
Forte	1425.8	799.7	-320.6	kg SO2 eq
Legato	1425.8	799.7	-307.5	kg SO2 eq
Espressivo	1425.8	799.7	-317.5	kg SO2 eq
Vivace	1425.8	799.7	-310.0	kg SO2 eq

Freshwater eutrophication - Avoided renovation materials				
	2020	2045	2070	
Facade ground N & S - Standard	4.109	0.000	-0.389	kg P eq
Facade ground N & S - Forte	4.109	0.000	-1.663	kg P eq
Facade ground N & S - Legato	4.109	0.000	-0.387	kg P eq
Facade ground N & S - Espressivo	4.109	0.000	-1.392	kg P eq
Facade ground N & S - Vivace	4.109	0.000	-0.300	kg P eq
Facade ground gables - Standard	1.584	0.000	-0.150	kg P eq
Facade ground gables - Forte	1.584	0.000	-0.641	kg P eq
Facade ground gables - Legato	1.584	0.000	-0.149	kg P eq
Facade ground gables - Espressivo	1.584	0.000	-0.536	kg P eq
Facade ground gables - Vivace	1.584	0.000	-0.115	kg P eq
Balcony at south facade	2.005	0.000	0.007	kg P eq
Facade north	3.460	0.000	-0.995	kg P eq
Facade gables - Standard	0.405	0.000	-1.278	kg P eq
Facade gables - Forte	0.405	0.000	-4.327	kg P eq
Facade gables - Legato	0.405	0.000	-1.275	kg P eq
Facade gables - Espressivo	0.405	0.000	-3.677	kg P eq
Facade gables - Vivace	0.405	0.000	-1.065	kg P eq
Windows south	22.255	10.059	-12.195	kg P eq
Windows north	11.267	5.097	-6.170	kg P eq
Windows gables	6.331	2.869	-3.462	kg P eq
Aggregated				
	2020	2045	2070	
Standard	51.4	18.0	-24.6	kg P eq
Forte	51.4	18.0	-29.4	kg P eq
Legato	51.4	18.0	-24.6	kg P eq
Espressivo	51.4	18.0	-28.4	kg P eq
Vivace	51.4	18.0	-24.3	kg P eq

Appendix J: Break-even point

Climate change

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Scenario 1 - Forte												
Canopy	154357	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	6676	6792	6850	6913	6981	7039	7097	7157	7228	7286	7346	7404
Gained - Avoided	-55134	-6792	-6850	-6913	-6981	-7039	-7097	-7157	-7228	-7286	-7346	-7404
Yearly Climate Change - Legato	-55134	-61926	-68776	-75689	-82670	-89709	-96805	-103962	-111190	-118476	-125822	-133225
Scenario 1 - Legato												
Canopy	154357	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	6485	6541	6585	6643	6639	6685	6739	6725	6783	6828	6883	6869
Gained - Avoided	-54944	-6541	-6585	-6643	-6639	-6685	-6739	-6725	-6783	-6828	-6883	-6869
Yearly Climate Change - Legato	-54944	-61485	-68070	-74713	-81352	-88036	-94776	-101501	-108284	-115112	-121995	-128864
Scenario 1 - Espressivo												
Canopy	154357	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	6947	7080	7196	7329	7404	7521	7653	7725	7858	7978	8107	8182
Gained - Avoided	-55405	-7080	-7196	-7329	-7404	-7521	-7653	-7725	-7858	-7978	-8107	-8182
Yearly Climate Change - Legato	-55405	-62485	-69681	-77010	-84414	-91935	-99588	-107314	-115171	-123149	-131256	-139438
Scenario 1 - Vivace												
Canopy	154357	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	7567	7777	7980	8240	8438	8641	8845	9043	9303	9505	9706	9908
Gained - Avoided	-56025	-7777	-7980	-8240	-8438	-8641	-8845	-9043	-9303	-9505	-9706	-9908
Yearly Climate Change - Vivace	-56025	-63802	-71782	-80021	-88460	-97100	-105945	-114988	-124291	-133796	-143501	-153409
Scenario 1 - Standard												
Canopy	154357	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002
Gained - Avoided	-54460	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002
Yearly Climate Change - Vivace	-54460	-60461	-66463	-72464	-78466	-84467	-90469	-96470	-102472	-108473	-114475	-120476
Scenario 2 - Forte												
Canopy	216535	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	8580	8729	8803	8885	8972	9046	9121	9198	9290	9364	9441	9515
Gained - Avoided	5140	-8729	-8803	-8885	-8972	-9046	-9121	-9198	-9290	-9364	-9441	-9515
Yearly Climate Change - Legato	5140	-3589	-12393	-21277	-30249	-39295	-48416	-57614	-66904	-76268	-85709	-95224
Scenario 2 - Legato												
Canopy	216535	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	8335	8407	8464	8537	8533	8591	8661	8643	8717	8776	8846	8828
Gained - Avoided	5385	-8407	-8464	-8537	-8533	-8591	-8661	-8643	-8717	-8776	-8846	-8828
Yearly Climate Change - Legato	5385	-3022	-11485	-20023	-28555	-37146	-45808	-54451	-63168	-71944	-80790	-89618
Scenario 2 - Espressivo												
Canopy	216535	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	8928	9099	9249	9419	9516	9666	9836	9929	10099	10253	10419	10516
Gained - Avoided	4792	-9099	-9249	-9419	-9516	-9666	-9836	-9929	-10099	-10253	-10419	-10516
Yearly Climate Change - Legato	4792	-4307	-13556	-22975	-32491	-42157	-51993	-61922	-72020	-82274	-92693	-103208
Scenario 2 - Vivace												
Canopy	216535	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	9725	9996	10256	10590	10845	11105	11367	11622	11956	12216	12474	12734
Gained - Avoided	3995	-9996	-10256	-10590	-10845	-11105	-11367	-11622	-11956	-12216	-12474	-12734
Yearly Climate Change - Vivace	3995	-6000	-16256	-26845	-37690	-48795	-60163	-71785	-83741	-95957	-108431	-121164
Scenario 2 - Standard												
Canopy	216535	0	0	0	0	0	0	0	0	0	0	0
Building parts	202815	0	0	0	0	0	0	0	0	0	0	0
Electricity	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713
Gained - Avoided	6007	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713
Yearly Climate Change - Vivace	6007	-1706	-9420	-17133	-24846	-32559	-40273	-47986	-55699	-63412	-71125	-78839

	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Scenario 1 - Forte															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	70444	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	7472	7535	7593	7708	7822	7928	8036	8150	8255	8369	8477	8589	8697	8858	8974
Gained - Avoided	-7472	-7535	-7593	-7708	-7822	-7928	-8036	-8150	-8255	-8369	-8477	-8589	-8697	-44596	-8974
Yearly Climate Change - Legato	-140697	-148233	-155826	-163534	-171356	-179285	-187320	-195470	-203725	-212095	-220572	-229161	-237858	-282453	-291427
Scenario 1 - Legato															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	72858	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	6926	6983	6969	7023	6987	6889	6863	6770	6740	6703	6620	6580	6486	6460	6363
Gained - Avoided	-6926	-6983	-6969	-7023	-6987	-6889	-6863	-6770	-6740	-6703	-6620	-6580	-6486	-39784	-6363
Yearly Climate Change - Legato	-135790	-142772	-149741	-156764	-163751	-170640	-177503	-184273	-191013	-197716	-204336	-210916	-217402	-257186	-263549
Scenario 1 - Espressivo															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	71110	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	8299	8431	8561	8624	8723	8817	8916	9008	9104	9213	9307	9404	9498	9597	9696
Gained - Avoided	-8299	-8431	-8561	-8624	-8723	-8817	-8916	-9008	-9104	-9213	-9307	-9404	-9498	-44669	-9696
Yearly Climate Change - Legato	-147737	-156169	-164729	-173353	-182076	-190893	-199808	-208816	-217920	-227133	-236440	-245844	-255342	-300012	-309708
Scenario 1 - Vivace															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	72665	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	10110	10309	10575	10788	10996	11208	11421	11635	11848	12003	12215	12429	12642	12855	13069
Gained - Avoided	-10110	-10309	-10575	-10788	-10996	-11208	-11421	-11635	-11848	-12003	-12215	-12429	-12642	-46372	-13069
Yearly Climate Change - Vivace	-163520	-173829	-184404	-195192	-206188	-217395	-228817	-240451	-252299	-264303	-276518	-288947	-301589	-347960	-361029
Scenario 1 - Standard															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	71726	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002
Gained - Avoided	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-40457	-6002
Yearly Climate Change - Vivace	-126478	-132480	-138481	-144483	-150484	-156486	-162487	-168489	-174490	-180492	-186493	-192495	-198496	-238954	-244955
Scenario 2 - Forte															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	93478	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	9603	9684	9759	9907	10053	10190	10327	10474	10610	10757	10894	11039	11177	11384	11534
Gained - Avoided	-9603	-9684	-9759	-9907	-10053	-10190	-10327	-10474	-10610	-10757	-10894	-11039	-11177	-24089	-11534
Yearly Climate Change - Legato	-104827	-114511	-124270	-134177	-144230	-154420	-164747	-175221	-185831	-196588	-207482	-218521	-229698	-253787	-265321
Scenario 2 - Legato															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	96837	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	8902	8974	8956	9026	8980	8854	8820	8700	8662	8615	8508	8457	8336	8302	8178
Gained - Avoided	-8902	-8974	-8956	-9026	-8980	-8854	-8820	-8700	-8662	-8615	-8508	-8457	-8336	-17647	-8178
Yearly Climate Change - Legato	-98520	-107494	-116450	-125476	-134455	-143310	-152130	-160830	-169493	-178108	-186615	-195072	-203408	-221055	-229233
Scenario 2 - Espressivo															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	94404	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	10666	10836	11003	11083	11210	11332	11458	11577	11700	11841	11962	12086	12207	12335	12462
Gained - Avoided	-10666	-10836	-11003	-11083	-11210	-11332	-11458	-11577	-11700	-11841	-11962	-12086	-12207	-24112	-12462
Yearly Climate Change - Legato	-113874	-124711	-135713	-146796	-158007	-169338	-180797	-192374	-204074	-215914	-227876	-239962	-252170	-276282	-288744
Scenario 2 - Vivace															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	96569	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	12994	13249	13592	13865	14132	14405	14679	14953	15227	15427	15699	15974	16248	16522	16796
Gained - Avoided	-12994	-13249	-13592	-13865	-14132	-14405	-14679	-14953	-15227	-15427	-15699	-15974	-16248	-26134	-16796
Yearly Climate Change - Vivace	-134158	-147407	-160999	-174863	-188995	-203400	-218079	-233032	-248259	-263686	-279385	-295359	-311606	-337740	-354536
Scenario 2 - Standard															
Canopy	0	0	0	0	0	0	0	0	0	0	0	0	0	96569	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0	0	106182	0
Electricity	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713
Gained - Avoided	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-17326	-7713
Yearly Climate Change - Vivace	-86552	-94265	-101978	-109692	-117405	-125118	-132831	-140544	-148258	-155971	-163684	-171397	-179111	-196436	-204149

	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058
Scenario 1 - Forte												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	9078	9195	9297	9405	9405	9405	9405	9405	9405	9405	9405	9405
Gained - Avoided	-9078	-9195	-9297	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405
Yearly Climate Change - Legato	-300505	-309701	-318998	-328403	-337808	-347213	-356618	-366024	-375429	-384834	-394239	-403644
Scenario 1 - Legato												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	6337	6301	6214	6178	6178	6178	6178	6178	6178	6178	6178	6178
Gained - Avoided	-6337	-6301	-6214	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178
Yearly Climate Change - Legato	-269886	-276186	-282400	-288577	-294755	-300933	-307110	-313288	-319465	-325643	-331820	-337998
Scenario 1 - Espressivo												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	9731	9830	9924	10020	10020	10020	10020	10020	10020	10020	10020	10020
Gained - Avoided	-9731	-9830	-9924	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020
Yearly Climate Change - Legato	-319439	-329269	-339193	-349213	-359233	-369253	-379273	-389293	-399313	-409333	-419352	-429372
Scenario 1 - Vivace												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	13282	13494	13707	13920	13920	13920	13920	13920	13920	13920	13920	13920
Gained - Avoided	-13282	-13494	-13707	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920
Yearly Climate Change - Vivace	-374311	-387805	-401512	-415432	-429352	-443273	-457193	-471113	-485034	-498954	-512874	-526794
Scenario 1 - Standard												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002
Gained - Avoided	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002
Yearly Climate Change - Vivace	-250957	-256958	-262960	-268961	-274963	-280964	-286966	-292967	-298969	-304970	-310972	-316973
Scenario 2 - Forte												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	11667	11818	11949	12088	12088	12088	12088	12088	12088	12088	12088	12088
Gained - Avoided	-11667	-11818	-11949	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088
Yearly Climate Change - Legato	-276988	-288806	-300755	-312843	-324930	-337018	-349105	-361193	-373281	-385368	-397456	-409543
Scenario 2 - Legato												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	8144	8098	7986	7939	7939	7939	7939	7939	7939	7939	7939	7939
Gained - Avoided	-8144	-8098	-7986	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939
Yearly Climate Change - Legato	-237377	-245475	-253461	-261400	-269340	-277279	-285218	-293158	-301097	-309037	-316976	-324916
Scenario 2 - Espressivo												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	12506	12634	12755	12878	12878	12878	12878	12878	12878	12878	12878	12878
Gained - Avoided	-12506	-12634	-12755	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878
Yearly Climate Change - Legato	-301250	-313884	-326639	-339517	-352394	-365272	-378150	-391027	-403905	-416783	-429660	-442538
Scenario 2 - Vivace												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	17071	17342	17616	17891	17891	17891	17891	17891	17891	17891	17891	17891
Gained - Avoided	-17071	-17342	-17616	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891
Yearly Climate Change - Vivace	-371607	-388949	-406565	-424456	-442346	-460237	-478127	-496018	-513908	-531799	-549689	-567580
Scenario 2 - Standard												
Canopy	0	0	0	0	0	0	0	0	0	0	0	0
Building parts	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713
Gained - Avoided	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713
Yearly Climate Change - Vivace	-211863	-219576	-227289	-235002	-242716	-250429	-258142	-265855	-273568	-281282	-288995	-296708

	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070
Scenario 1 - Forte												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-94410
Building parts	0	0	0	0	0	0	0	0	0	0	0	-28976
Electricity	9405	9405	9405	9405	9405	9405	9405	9405	9405	9405	9405	0
Gained - Avoided	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-9405	-65434
Yearly Climate Change - Legato	-413049	-422454	-431859	-441264	-450669	-460075	-469480	-478885	-488290	-497695	-507100	-572534
Scenario 1 - Legato												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-81126
Building parts	0	0	0	0	0	0	0	0	0	0	0	-28976
Electricity	6178	6178	6178	6178	6178	6178	6178	6178	6178	6178	6178	0
Gained - Avoided	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-6178	-52150
Yearly Climate Change - Legato	-344175	-350353	-356530	-362708	-368886	-375063	-381241	-387418	-393596	-399773	-405951	-458101
Scenario 1 - Espressivo												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-91169
Building parts	0	0	0	0	0	0	0	0	0	0	0	-28018
Electricity	10020	10020	10020	10020	10020	10020	10020	10020	10020	10020	10020	0
Gained - Avoided	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-10020	-63151
Yearly Climate Change - Legato	-439392	-449412	-459432	-469452	-479472	-489492	-499512	-509532	-519551	-529571	-539591	-602743
Scenario 1 - Vivace												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-80273
Building parts	0	0	0	0	0	0	0	0	0	0	0	-24797
Electricity	13920	13920	13920	13920	13920	13920	13920	13920	13920	13920	13920	0
Gained - Avoided	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-13920	-55476
Yearly Climate Change - Vivace	-540715	-554635	-568555	-582476	-596396	-610316	-624237	-638157	-652077	-665997	-679918	-735394
Scenario 1 - Standard												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-87506
Building parts	0	0	0	0	0	0	0	0	0	0	0	-26935
Electricity	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	6002	0
Gained - Avoided	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-6002	-60571
Yearly Climate Change - Vivace	-322975	-328976	-334978	-340979	-346981	-352982	-358984	-364985	-370987	-376989	-382990	-443561
Scenario 2 - Forte												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-145134
Building parts	0	0	0	0	0	0	0	0	0	0	0	-28976
Electricity	12088	12088	12088	12088	12088	12088	12088	12088	12088	12088	12088	0
Gained - Avoided	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-12088	-116158
Yearly Climate Change - Legato	-421631	-433719	-445806	-457894	-469981	-482069	-494157	-506244	-518332	-530419	-542507	-658665
Scenario 2 - Legato												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-123081
Building parts	0	0	0	0	0	0	0	0	0	0	0	-25049
Electricity	7939	7939	7939	7939	7939	7939	7939	7939	7939	7939	7939	0
Gained - Avoided	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-7939	-98032
Yearly Climate Change - Legato	-332855	-340795	-348734	-356674	-364613	-372553	-380492	-388431	-396371	-404310	-412250	-510282
Scenario 2 - Espressivo												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-139754
Building parts	0	0	0	0	0	0	0	0	0	0	0	-28018
Electricity	12878	12878	12878	12878	12878	12878	12878	12878	12878	12878	12878	0
Gained - Avoided	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-12878	-111736
Yearly Climate Change - Legato	-455416	-468294	-481171	-494049	-506927	-519804	-532682	-545560	-558437	-571315	-584193	-695929
Scenario 2 - Vivace												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-121665
Building parts	0	0	0	0	0	0	0	0	0	0	0	-24797
Electricity	17891	17891	17891	17891	17891	17891	17891	17891	17891	17891	17891	0
Gained - Avoided	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-17891	-96869
Yearly Climate Change - Vivace	-585470	-603361	-621251	-639142	-657032	-674923	-692813	-710704	-728594	-746485	-764375	-861244
Scenario 2 - Standard												
Canopy	0	0	0	0	0	0	0	0	0	0	0	-121665
Building parts	0	0	0	0	0	0	0	0	0	0	0	-24797
Electricity	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	7713	0
Gained - Avoided	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-7713	-96869
Yearly Climate Change - Vivace	-304421	-312135	-319848	-327561	-335274	-342987	-350701	-358414	-366127	-373840	-381554	-478422

Appendix K: Sensitivity ratio

Sensitivity ratio of climate Change with a 10 % increase in input							
			Forte	Legato	Espressivo	Vivace	Standard
Building materials	Balcony at south facade	Scenario 1	0.03	0.03	0.03	0.02	0.04
		Scenario 2	0.02	0.03	0.02	0.02	0.03
	Facade gables	Scenario 1	0.03	0.04	0.03	0.03	0.05
		Scenario 2	0.03	0.04	0.03	0.03	0.05
	Facade ground level gables	Scenario 1	0.01	0.02	0.01	0.01	0.02
		Scenario 2	0.01	0.02	0.01	0.01	0.02
	Facade ground level north and south	Scenario 1	0.04	0.04	0.03	0.03	0.05
		Scenario 2	0.03	0.04	0.03	0.03	0.05
	Facade north	Scenario 1	0.02	0.02	0.02	0.01	0.02
		Scenario 2	0.02	0.02	0.01	0.01	0.02
	Windows gables	Scenario 1	0.06	0.08	0.06	0.05	0.08
		Scenario 2	0.05	0.07	0.05	0.04	0.07
	Windows north	Scenario 1	0.11	0.14	0.11	0.09	0.15
		Scenario 2	0.10	0.13	0.09	0.08	0.14
	Windows south	Scenario 1	0.22	0.28	0.21	0.17	0.29
		Scenario 2	0.19	0.25	0.18	0.15	0.27
Canopy materials	ETFE	Scenario 1	-0.22	-0.28	-0.21	-0.18	-0.29
		Scenario 2	-0.27	-0.36	-0.25	-0.21	-0.38
	Silicone sealing	Scenario 1	-0.01	-0.02	-0.01	-0.01	-0.02
		Scenario 2	-0.01	-0.02	-0.01	-0.01	-0.02
	Timber	Scenario 1	0.04	0.02	0.03	0.01	0.03
		Scenario 2	0.06	0.04	0.05	0.02	0.04
	Aluminum profiles	Scenario 1	-0.02	-0.02	-0.01	-0.01	-0.02
		Scenario 2	-0.02	-0.02	-0.02	-0.01	-0.03
	Glass	Scenario 1	-0.05	-0.06	-0.04	-0.04	-0.06
		Scenario 2	-0.58	-0.77	-0.55	-0.44	-0.82
	Pump	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Steel	Scenario 1	-0.15	-0.19	-0.14	-0.12	-0.19
		Scenario 2	-0.29	-0.38	-0.28	-0.22	-0.41
Energy	Electricity	Scenario 1	0.76	0.73	0.77	0.83	0.70
		Scenario 2	0.84	0.83	0.85	0.90	0.82

Sensitivity ratio of Ozone depletion with a 10 % increase in input							
			Forte	Legato	Espressivo	Vivace	Standard
Building materials	Balcony at south facade	Scenario 1	0.00	0.01	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Facade gables	Scenario 1	-0.01	-0.02	-0.01	-0.01	-0.01
		Scenario 2	-0.01	-0.02	-0.01	-0.01	-0.01
	Facade ground level gables	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Facade ground level north and south	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Facade north	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Windows gables	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Windows north	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Windows south	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
Canopy materials	ETFE	Scenario 1	-0.01	-0.01	-0.01	-0.01	-0.02
		Scenario 2	-0.01	-0.01	-0.01	-0.01	-0.01
	Silicone sealing	Scenario 1	0.00	-0.01	0.00	0.00	-0.01
		Scenario 2	0.00	-0.01	0.00	0.00	-0.01
	Timber	Scenario 1	0.04	0.12	0.06	0.04	0.06
		Scenario 2	0.05	0.15	0.08	0.05	0.09
	Aluminum profiles	Scenario 1	0.00	-0.01	-0.01	0.00	-0.01
		Scenario 2	0.00	-0.01	-0.01	0.00	-0.01
	Glass	Scenario 1	-0.01	-0.01	-0.01	-0.01	-0.01
		Scenario 2	-0.06	-0.14	-0.08	-0.06	-0.12
	Pump	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Steel	Scenario 1	-0.01	-0.01	-0.01	-0.01	-0.01
		Scenario 2	-0.01	-0.02	-0.01	-0.01	-0.02
Energy	Electricity	Scenario 1	0.99	0.95	0.98	0.99	1.00
		Scenario 2	0.98	0.92	0.96	0.98	0.97

Sensitivity ratio of Photochemical oxidant formation with a 10 % increase in input							
			Forte	Legato	Espressivo	Vivace	Standard
Building materials	Balcony at south facade	Scenario 1	0.03	0.04	0.03	0.03	0.05
		Scenario 2	0.03	0.04	0.02	0.02	0.04
	Facade gables	Scenario 1	0.01	0.01	0.01	0.01	0.02
		Scenario 2	0.01	0.01	0.01	0.01	0.02
	Facade ground level gables	Scenario 1	0.01	0.01	0.01	0.01	0.02
		Scenario 2	0.01	0.01	0.01	0.01	0.02
	Facade ground level north and south	Scenario 1	0.03	0.04	0.03	0.02	0.05
		Scenario 2	0.03	0.04	0.02	0.02	0.04
	Facade north	Scenario 1	0.02	0.02	0.02	0.01	0.03
		Scenario 2	0.02	0.02	0.01	0.01	0.03
	Windows gables	Scenario 1	0.05	0.07	0.04	0.04	0.07
		Scenario 2	0.04	0.06	0.04	0.03	0.07
	Windows north	Scenario 1	0.10	0.12	0.08	0.07	0.14
		Scenario 2	0.08	0.10	0.07	0.06	0.12
	Windows south	Scenario 1	0.19	0.23	0.16	0.14	0.27
		Scenario 2	0.16	0.20	0.13	0.12	0.24
Canopy materials	ETFE	Scenario 1	-0.17	-0.22	-0.14	-0.13	-0.25
		Scenario 2	-0.20	-0.27	-0.17	-0.15	-0.32
	Silicone sealing	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	-0.01	0.00	0.00	-0.01
	Timber	Scenario 1	0.03	0.01	0.02	0.01	0.02
		Scenario 2	0.05	0.02	0.04	0.01	0.03
	Aluminum profiles	Scenario 1	-0.02	-0.03	-0.02	-0.02	-0.03
		Scenario 2	-0.03	-0.04	-0.02	-0.02	-0.04
	Glass	Scenario 1	-0.05	-0.06	-0.04	-0.04	-0.07
		Scenario 2	-0.62	-0.81	-0.52	-0.46	-0.98
	Pump	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Steel	Scenario 1	-0.16	-0.20	-0.13	-0.12	-0.23
		Scenario 2	-0.30	-0.38	-0.25	-0.22	-0.46
Energy	Electricity	Scenario 1	0.80	0.79	0.84	0.86	0.73
		Scenario 2	0.87	0.87	0.90	0.92	0.84

Sensitivity ratio of Terrestrial acidification with a 10 % increase in input							
			Forte	Legato	Espressivo	Vivace	Standard
Building materials	Balcony at south facade	Scenario 1	0.04	0.04	0.03	0.03	0.06
		Scenario 2	0.03	0.04	0.03	0.02	0.05
	Facade gables	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.01	0.00	0.00	0.01
	Facade ground level gables	Scenario 1	0.01	0.01	0.01	0.01	0.01
		Scenario 2	0.01	0.01	0.01	0.01	0.01
	Facade ground level north and south	Scenario 1	0.02	0.02	0.02	0.02	0.03
		Scenario 2	0.02	0.02	0.02	0.01	0.03
	Facade north	Scenario 1	0.02	0.02	0.02	0.01	0.03
		Scenario 2	0.02	0.02	0.01	0.01	0.03
	Windows gables	Scenario 1	0.07	0.08	0.06	0.05	0.11
		Scenario 2	0.06	0.07	0.05	0.04	0.10
	Windows north	Scenario 1	0.12	0.15	0.11	0.09	0.19
		Scenario 2	0.11	0.13	0.09	0.08	0.19
	Windows south	Scenario 1	0.24	0.29	0.22	0.19	0.38
		Scenario 2	0.21	0.26	0.19	0.16	0.36
Canopy materials	ETFE	Scenario 1	-0.17	-0.21	-0.15	-0.13	-0.27
		Scenario 2	-0.21	-0.26	-0.18	-0.16	-0.37
	Silicone sealing	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	-0.01
	Timber	Scenario 1	0.02	0.02	0.02	0.01	0.04
		Scenario 2	0.04	0.03	0.03	0.02	0.05
	Aluminum profiles	Scenario 1	-0.02	-0.02	-0.01	-0.01	-0.03
		Scenario 2	-0.02	-0.02	-0.02	-0.01	-0.03
	Glass	Scenario 1	-0.05	-0.06	-0.04	-0.04	-0.08
		Scenario 2	-0.63	-0.78	-0.55	-0.47	-1.15
	Pump	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Steel	Scenario 1	-0.09	-0.10	-0.08	-0.07	-0.14
		Scenario 2	-0.17	-0.21	-0.15	-0.13	-0.30
Energy	Electricity	Scenario 1	0.73	0.69	0.76	0.80	0.56
		Scenario 2	0.81	0.78	0.83	0.87	0.68

Sensitivity ratio of Freshwater eutrophication with a 10 % increase in input							
			Forte	Legato	Espressivo	Vivace	Standard
Building materials	Balcony at south facade	Scenario 1	0.01	0.01	0.01	0.01	0.02
		Scenario 2	0.01	0.01	0.01	0.01	0.02
	Facade gables	Scenario 1	-0.03	-0.02	-0.02	0.00	-0.01
		Scenario 2	-0.02	0.00	-0.01	0.00	-0.01
	Facade ground level gables	Scenario 1	0.01	0.01	0.00	0.01	0.02
		Scenario 2	0.00	0.01	0.00	0.00	0.01
	Facade ground level north and south	Scenario 1	0.02	0.01	0.01	0.02	0.04
		Scenario 2	0.01	0.02	0.01	0.01	0.04
	Facade north	Scenario 1	0.02	0.01	0.01	0.01	0.03
		Scenario 2	0.01	0.01	0.01	0.01	0.02
	Windows gables	Scenario 1	0.03	0.03	0.03	0.02	0.06
		Scenario 2	0.03	0.02	0.02	0.02	0.05
	Windows north	Scenario 1	0.06	0.05	0.05	0.04	0.11
		Scenario 2	0.05	0.04	0.04	0.03	0.09
	Windows south	Scenario 1	0.13	0.11	0.09	0.08	0.21
		Scenario 2	0.10	0.09	0.07	0.07	0.19
Canopy materials	ETFE	Scenario 1	-0.16	-0.16	-0.12	-0.12	-0.32
		Scenario 2	-0.18	-0.18	-0.13	-0.14	-0.40
	Silicone sealing	Scenario 1	0.00	0.00	0.00	0.00	-0.01
		Scenario 2	0.00	0.00	0.00	0.00	-0.01
	Timber	Scenario 1	0.11	0.02	0.07	0.01	0.04
		Scenario 2	0.16	0.03	0.10	0.02	0.06
	Aluminum profiles	Scenario 1	-0.03	-0.02	-0.02	-0.02	-0.05
		Scenario 2	-0.03	-0.03	-0.02	-0.02	-0.06
	Glass	Scenario 1	-0.03	-0.03	-0.02	-0.02	-0.06
		Scenario 2	-0.39	-0.33	-0.28	-0.26	-0.75
	Pump	Scenario 1	0.00	0.00	0.00	0.00	0.00
		Scenario 2	0.00	0.00	0.00	0.00	0.00
	Steel	Scenario 1	-0.46	-0.38	-0.33	-0.29	-0.79
		Scenario 2	-0.83	-0.70	-0.59	-0.53	-1.63
Energy	Electricity	Scenario 1	0.88	0.98	0.92	0.97	0.92
		Scenario 2	0.90	1.01	0.94	1.01	1.03