Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

EFFECT OF SERVICE LIFE IN THE EMISSION ASSESSMENT OF VENTILATION SYSTEMS

A case study in an office building

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Keywords: Ventilation systems, replacement scenarios, lifetime, embodied emissions.

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Preface

Acknowledgements

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The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society. Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Mære Campus, Ydalir in Elverum, Campus Evenstad, Ny by-ny flyplass Bodø, and Zero Village Bergen.

The ZEN Research Centre is a eight year project ending in 2025, and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Summary

In the construction sector, the total carbon footprint of a building measures the greenhouse gas (GHG) emissions associated with all the stages in the building's life cycle, including the replacement of elements over the years. The calculations are very relevant for installation systems, which generally have a shorter lifetime than the building itself and need to be replaced for proper operation of the building. Ventilation systems, particularly, are complex and include diverse components of various materials, functions and service lifetime. The literature data about the service life in years for the components is fragmented, different in diverse guidelines, or not specified for each composing component.

The impact of replacing ventilation system components was studied in a case study in an office building in Bergen, Norway. The emissions from the replacement were assessed for three replacement scenarios during the service life of 60 years. The first scenario was based on the experience of specialists dealing with ventilation systems and data from the literature. Two other border scenarios were considered: one frequent and one rare replacement of components through the years.

From the expert-assumed values, the emissions from the replacement are approximately 1.5 times higher than the emissions from the production of the components. When a frequent substitution occurs over the years, the emissions from the replacement cover approximately 2.5 times the emissions from the production, while when the replacement occurs rarely, the emissions are less than half of the embodied emissions. The assessment showed high fluctuations in the results when different scenarios were applied, highlighting the need for further work in the field to determine and unify the service life of components. A comprehensive database with service lives for installation components, and an increase of EPDs for such products from the producers would facilitate the assessment and integration of the carbon emissions of such systems in the overall carbon footprint of the building.

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1. Background

In the book "How Buildings Learn: What Happens After They're Built", Brand discusses the composition of buildings through the concept of Shearing Layers [1]. According to Brand, any building mainly comprises six shearing layers, known as 6S (Site, Structure, Skin, Services, Space Plan and Stuff), as visualised in Figure 1. Because of the different rates of change of its components, a building is constantly tearing itself apart.

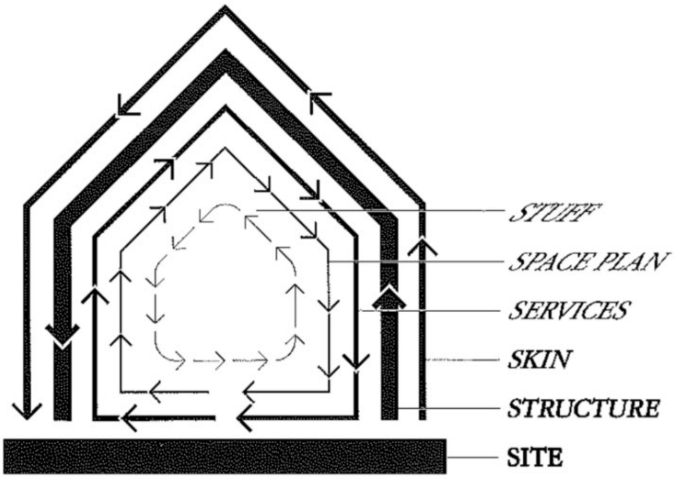

Figure 1: Shearing Layers from How Buildings Learn by Stewart Brand [1]

The service layer is considered the veins of a building. It comprises communications and electrical wiring, plumbing, fire sprinkler systems, HVAC (heating, ventilating, and air conditioning) systems, and moving parts like elevators and escalators. Due to continuous operation, they wear out earlier than the structure or building skin, and many buildings are demolished earlier than expected when it is difficult to replace or upgrade outdated services [2].

Ventilation is a crucial element of any HVAC system because it impacts both indoor air quality and energy efficiency. Proper ventilation prevents undesirable odours, reduces pollutant gases (correlated with carbon dioxide), and restrains respiratory diseases; therefore, it should be maintained and replaced accordingly. However, generic and fragmentary information is available about the service lifetime of the ventilation system components and their replacement rate during the building lifetime.

Apart from the effects on indoor air quality and energy efficiency, the replacement of the ventilation system also affects the carbon footprint assessment of the building during its service life. In this regard, several Life Cycle Assessment (LCA) studies have been undertaken to assess the environmental impact of installation systems from a lifecycle perspective [3], [4], [5]. The results show that their replacement has a higher impact than the production stage, and therefore, a good and planned database of replacement intervals needs to be available for the system components. The effort must be followed with information provided by the producers of these systems through Environmental System Declarations (EPDs) that specify the components' environmental impact and reference service life [6].

This memo studies the impact of replacing the ventilation system on the carbon footprint of a building during the service lifetime. A case study building located in Bergen, Norway, was used to study and compare the impact of different replacement scenarios. Since empirical replacement intervals are unavailable for all the specific components, estimated service life has been assumed through a literature review and a workshop organised with experts in the ventilation field. The range of replacement scenarios has been considered to highlight the impact of replacement on overall emissions and the importance of further studies to determine the service lifetime of the components.

2. Case Study

A BREEAM Outstanding office building built in 2013 is investigated as a case study. The building is located in Bergen, on the western coast of Norway. The building is four stories high, with a gross floor area of 2,998 m^2. The maximum airflow rate of the ventilation system is approximately 12 $m^3/h.m^2$.

The greenhouse gas calculations for the ventilation system of the case building were performed by Bergsdal et al. as part of the efforts to document a comprehensive library for embodied emissions in ventilation systems [7]. The assessment encompasses the production stage of the components (modules A1-A3) according to the Norwegian standard for greenhouse gas calculations for buildings NS 3720 [8]. Calculations were performed with SimaPro, a specialised environmental assessment software [9]. The results of the carbon footprint for the ventilation system components used during the construction of the building are given in Table 1.

Table 1: The embodied emissions of the ventilation system components.

Component	**Global warming [$kgCO_2$-eq.]**	**Ratio [%]**
Air handling units	19 971.9	31.8 %
Ducts, circular	19 083.4	30.3 %
Ducts, rectangular	2 431.3	3.9 %
Bends, circular	2 580.1	4.1 %
Bends, rectangular	1 757.8	2.8 %
Flow dampers	2 889.8	4.6 %
Outlets	400.6	0.6 %
Reductions, circular	332.6	0.5 %
Reductions, rectangular	527.2	0.8 %
Silencers, circular	3 033.1	4.8 %
Silencers, rectangular	1 371.0	2.2 %
Supply air units	3 724.1	5.9 %
T-bends, circular	931.8	1.5 %
Joint parts, circular	55.7	0.1 %
Joint parts, rectangular	184.3	0.3 %
End caps, circular	196.3	0.3 %
End caps, rectangular	14.7	0.0 %
Boxes	2 215.3	3.5 %
Extract air valves	134.3	0.2 %
Plenum boxes	1 065.8	1.7 %
Total [$kgCO_2$-eq.]	**62 900.8**	**100 %**
[$kgCO_2$-eq./m^2]	**20.98**	
[$kgCO_2$-eq./(m^2 year)]	**0.35**	

The main contributors to the embodied emissions are the air handling units and circular ducts, which have a roughly equal share and cover 62.1% of the total emissions. The other component types contribute the rest, each not exceeding 6% of the total, with eight contributing less than 1%.

The total estimated climate footprint from the ventilation system of the case building is 62 900.8 $kgCO_2$-eq., with an estimated 21 $kgCO_2$-eq./m^2 for the entire ventilation system. Considering the building's service lifetime of 60 years, the unit emissions of the ventilation system are 0.35 $kgCO_2$-eq./m^2 per year. The results from the ventilation system need to be added to the GHG calculations of other building elements for an extensive overview of the total emissions of the building.

3. Impact of Replacement

The carbon footprint of the replacement phases needs to be incorporated in the total emission assessment because replacement (B4) is a mandatory module in the emission declaration requirements [10]. Following NS 3720, the greenhouse gas calculation must comprise a 60-year lifespan for the building. Like most installation systems, ventilation systems are not included in the minimum emission declaration requirements. However, it is strongly encouraged to include as many building elements as possible in the assessment. The components of ventilation systems have a shorter service lifetime than the building itself and need to be replaced periodically for optimal building operation. Therefore, studying and considering the effect of the replacement is necessary for the emission assessment during the entire lifespan.

The ventilation system comprises many components of different materials with different service lifetimes. However, in the standards providing data about the life span of building components, the empirical values are not given for every component of the ventilation system [11]. Some values of changing intervals in years are given in the SINTEF guideline 700.320, but they comprise only the construction elements [13]. Guideline 700.307 provides definitions and how to use lifetime data for buildings and building components but does not provide lifetime values in years [12]. A report about lifetimes in practice further explains the difference between the technical and functional values but does not provide specific values for each ventilation system component [14]. Therefore, the baseline lifetime estimates used here are based on the values provided by Multiconsult in ZEN Report 52 [15]. The challenge of assigning reasonable estimates for component lifetimes was further discussed with ZEN partners and the industry in a workshop organised by FME ZEN, confirming the lack of good empirically-based lifetime estimates. Other international guidelines concerning lifetimes, such as the Danish [16] and German [17] ones, were considered in the lifetime assignment.

In many literature studies, the lifetime in years is given in a range due to the complexity of assigning a unique value for various components. Therefore, another scenario with a low estimated lifetime for the components was defined, i.e. a higher number of replacements during the building's lifespan. The third scenario considers a high life expectancy for the components, meaning that most do not need to be replaced during the lifetime, while the rest only a few times.

The number of replacements for the lifetime period of 60 years was calculated using the equation (1) given in the standard:

$$Number\ of\ replacements = \frac{Required\ service\ life\ of\ the\ building}{Estimated\ service\ life\ of\ the\ product} - 1 \qquad (1)$$

The results of the replacement module B4 for each scenario are given in Table 2.

Table 2: The emissions of ventilation system components for different replacement scenarios.

Component	Production A1–A3		Replacement B4 (Assumed service life)				Replacement B4 (Low service life)				Replacement B4 (High service life)			
	Global warming [kgCO$_2$eq]	Ratio [%]	Service life [years]	Replacement [number]	Global warming [kgCO$_2$eq]	Ratio [%]	Service life [years]	Replacement [number]	Global warming [kgCO$_2$eq]	Ratio [%]	Service life [years]	Replacement [number]	Global warming [kgCO$_2$eq]	Ratio [%]
Air handling units	19 971.9	31.8 %	20	2	39 943.7	43.1 %	15	3	59 915.6	37.8 %	30	1	19 971.9	74.0 %
Ducts, circular	19 083.4	30.3 %	30	1	19 083.4	20.6 %	20	2	38 166.9	24.1 %	60	0	0	0 %
Ducts, rectangular	2 431.3	3.9 %	30	1	2 431.3	2.6 %	20	2	4 862.6	3.1 %	60	0	0	0 %
Bends, circular	2 580.1	4.1 %	30	1	2 580.1	2.8 %	20	2	5 160.1	3.3 %	60	0	0	0 %
Bends, rectangular	1 757.8	2.8 %	30	1	1 757.8	1.9 %	20	2	3 515.5	2.2 %	60	0	0	0 %
Flow dampers	2 889.8	4.6 %	15	3	8 669.4	9.3 %	10	5	14 449.0	9.1 %	30	1	2 889.8	10.7 %
Outlets	400.6	0.6 %	20	2	801.1	0.9 %	15	3	1 201.7	0.8 %	30	1	400.6	1.5 %
Reductions, circular	332.6	0.5 %	30	1	332.6	0.4 %	20	2	665.1	0.4 %	60	0	0	0 %
Reductions, rectangular	527.2	0.8 %	30	1	527.2	0.6 %	20	2	1 054.4	0.7 %	60	0	0	0 %
Silencers, circular	3 033.1	4.8 %	30	1	3 033.1	3.3 %	20	2	6 066.1	3.8 %	60	0	0	0 %
Silencers, rectangular	1 371.0	2.2 %	30	1	1 371.0	1.5 %	20	2	2 742.0	1.7 %	60	0	0	0 %
Supply air units	3 724.1	5.9 %	20	2	7 448.1	8.0 %	15	3	11 172.2	7.0 %	30	1	3 724.1	13.8 %
T-bends, circular	931.8	1.5 %	30	1	931.8	1.0 %	20	2	1 863.6	1.2 %	60	0	0	0 %
Joint parts, circular	55.7	0.1 %	30	1	55.7	0.1 %	20	2	111.3	0.1 %	60	0	0	0 %
Joint parts, rectangular	184.3	0.3 %	30	1	184.3	0.2 %	20	2	368.5	0.2 %	60	0	0	0 %
End caps, circular	196.3	0.3 %	30	1	196.3	0.2 %	20	2	392.7	0.2 %	60	0	0	0 %
End caps, rectangular	14.7	0.0 %	30	1	14.7	0.0 %	20	2	29.4	0.0 %	60	0	0	0 %
Boxes	2 215.3	3.5 %	30	1	2 215.3	2.4 %	20	2	4 430.6	2.8 %	60	0	0	0 %
Extract air valves	134.3	0.2 %	30	1	134.3	0.1 %	20	2	268.6	0.2 %	60	0	0	0 %
Plenum boxes	1 065.8	1.7 %	30	1	1 065.8	1.1 %	20	2	2 131.6	1.3 %	60	0	0	0 %
Total [kgCO$_2$-eq.]	**62 900.8**	**100.0 %**			**92 776.9**	**100.0 %**			**158 567.6**	**100.0 %**			**26 986.3**	**100.0 %**
[kgCO$_2$-eq./m^2]	**20.98**				**30.95**				**52.89**				**9.00**	
[kgCO$_2$-eq./(m^2 year)]	**0.35**				**0.52**				**0.88**				**0.15**	
B4/(A1-A3)					**147 %**				**252 %**				**43 %**	

In the carbon footprint assessment, the emissions from the replacement module B4 must be added to the emissions from the production stage A1-A3. The results emphasise the importance of service life definition in the total calculations, significantly affecting the emissions of the replacement stage.
The choice of service lifetimes in low and high scenarios was purely theoretical to demonstrate the impact of the lifetime assumptions. The lifetime of each component in all three scenarios was considered in a way that every component has a different number of replacements in each scenario. As can be noted from Table 2, the lifetime of each component in all three scenarios was considered in a way that every component has a different number of replacements in each scenario. Such different replacement intervals better highlight the effect of the replacement on the overall emission calculations.

For the scenario with data collected from the literature and the expert participatory approach, the emissions from the replacement are 47% higher than the initial production phase. Most components must be replaced once during the 60 years of building operation, while air handling units, outlets, and supply air units need to be replaced twice. Flow dampers are essential to stop or regulate the airflow inside a duct or air handler; therefore, they must be replaced more often (three times) to avoid high energy costs.

When the components need to be replaced more often (low service life), the replacement impact is 2.52 times higher than the production impact. The higher effect derives from the fact that components must be replaced at least twice during the building's service life. In this scenario, air handling units, outlets, and supply air units need to be replaced three times, while flow dampers need to be replaced 5 times in the lifespan interval of 60 years.

When the service life of most components is assumed to be the same as the service life of the building (60 years), the impact from replacement is 43% of the emissions from the production stage. This ratio comes from replacing air handling units, flow dampers, outlets, and supply air units, which must be replaced once during the operational phase.

The results of Table 2 are also presented in Figures 2 and 3 to highlight the impact of each component in the overall assessment. The circular and rectangular elements have been grouped to highlight the impact of the main components in the total assessment.

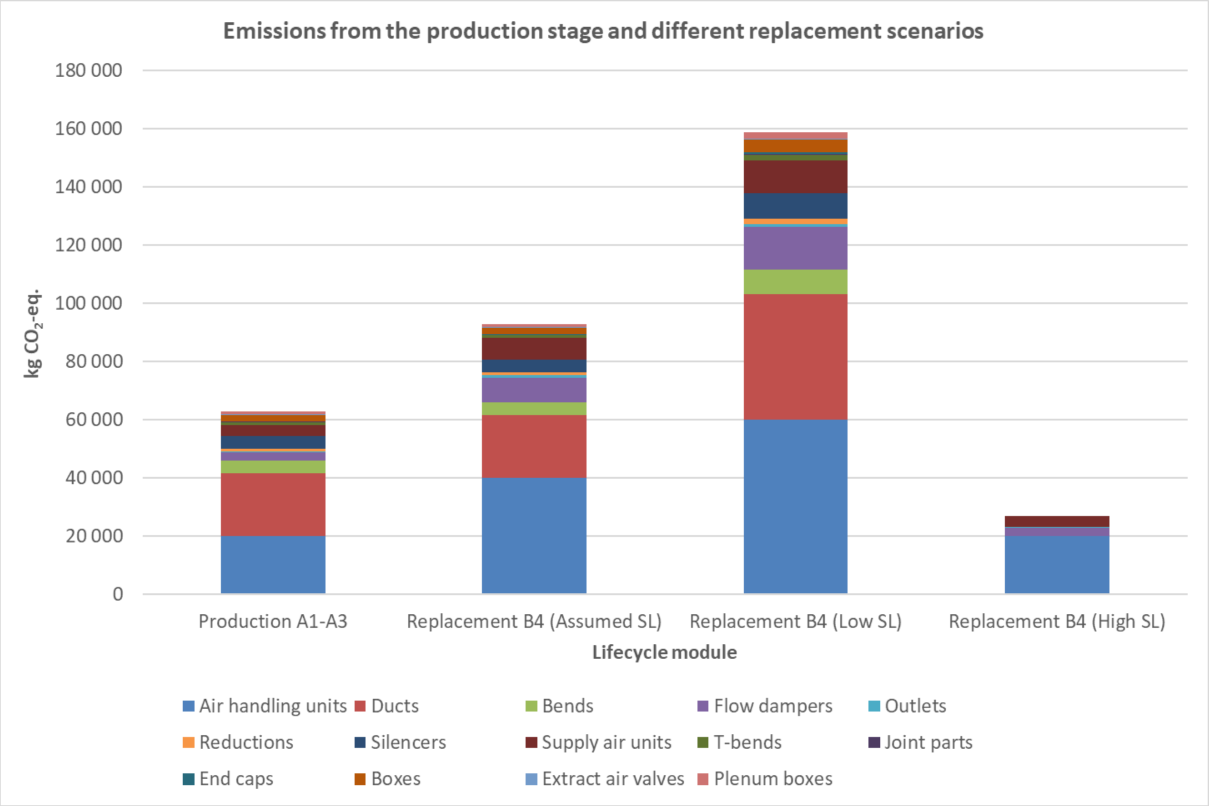

Figure 2: The impact of replacement scenarios in the overall emissions assessment.

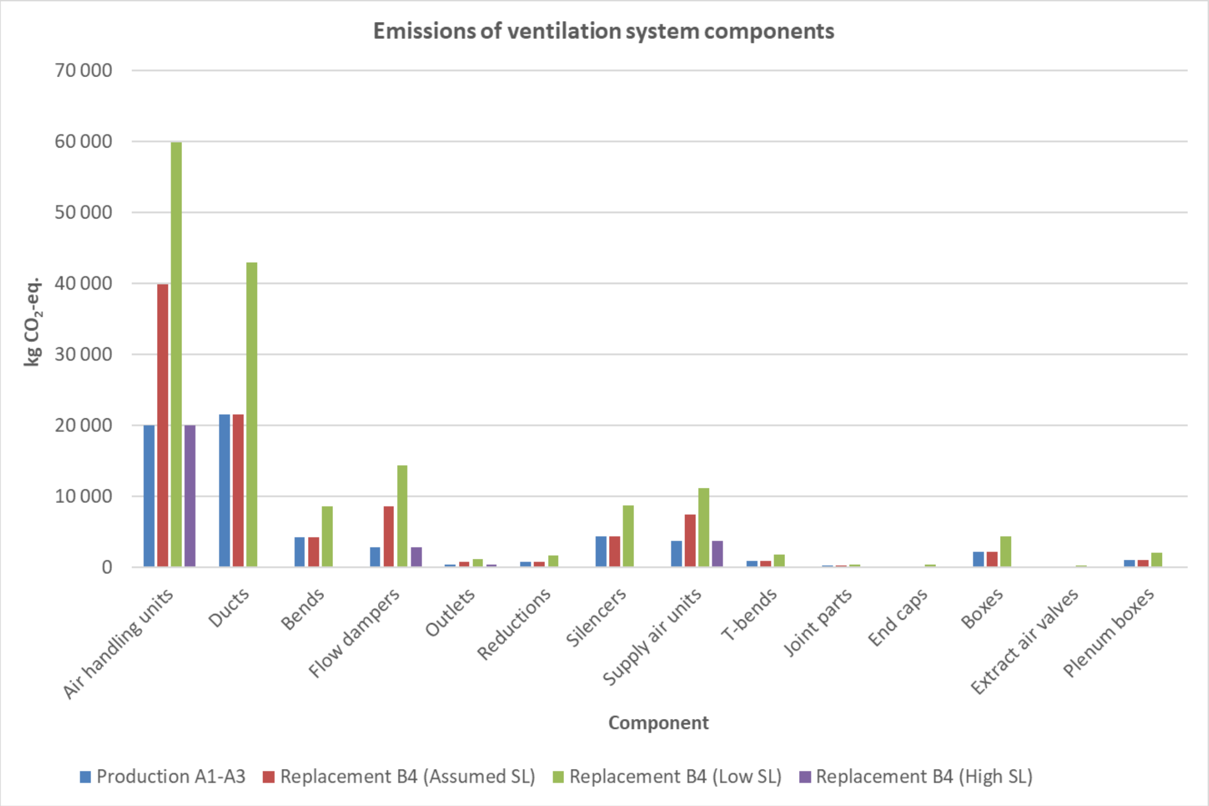

Figure 3: The impact of ventilation system components in the overall emissions assessment.

Figure 2 visually demonstrates that the emissions from the replacement using assumed values through an expert participatory approach are almost 1.5 times bigger than the emissions from the production of the components. When a more frequent replacement rate is utilised, the impact increases more than 2.5 times. In case it is assumed that most of the components do not need to be replaced or replaced only once during the service life, the impact of replacement is less than half of the emissions from the production of the components.

Figure 3 compares each component's share in the production stage calculations or when different replacement scenarios are applied. Air handling units must be replaced in all scenarios and cover the highest share of the emissions. When needed to be replaced, ducts also cover a significant part of emissions in module B4. Flow dampers, supply air units, silencers, and bends are also in the range of 5-10% of the total emissions in the scenarios where they need to be replaced (assumed or low service life). The other components account for under 3% of the total emissions in these scenarios. A difference is noted in the scenario with a high service life for the components, where only four of them must be replaced in 60 years. Replacement of air handling units accounts for 74% of the total replacement emissions, while flow dampers, outlets, and supply air constitute the rest.

4. Results

Replacement is an obligatory module of greenhouse gas accounting, and it must be assessed carefully, especially for elements with a service life shorter than the building, such as ventilation systems, which are compounded by various components with different material compositions, functions, and service lifetimes. However, the reference lifetimes for the ventilation system components are missing, have different values in different literature, or are given over a range of years, increasing the uncertainty for the replacement calculations. Therefore, it is important to study and determine reference service life values for such components, which can be unified at a national or international level.

Three replacement scenarios were used to evaluate and compare the impact of replacement on the overall emission calculations. A four-story office building located in Bergen was used for the assessment. In addition to a default lifetime scenario, two border scenarios with a high and a low replacement rate of the ventilation system components were applied to achieve a broader spectrum of results.

The estimations are compared with the emissions from the production of ventilation system components. The replacement applying expert-assigned lifetimes gives 1.47 times higher emissions than the production stage. When a high frequency of replacements is followed, the replacement emissions account for 252% of the emissions from the production stage. In contrast, when the replacement does not occur frequently, the emissions from the replacement are 43% of the embodied emissions. Such a wide range of results recommends further studies in the service life specification for ventilation system components. A table with unified service life values would encourage the inclusion of emissions from installation systems in the environmental assessment of buildings. In addition, an increase of EPDs for ventilation system components from the producers would facilitate the estimations and incorporation in the total carbon calculations. Finally, the wide range of results also strongly motivates the development and implementation of ventilation components with long or extended lifetimes.

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