Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

NTNU SINTEF

LIFE CYCLE ASSESSMENT OF VENTILATION SYSTEMS

Experience from FME ZEN and current knowledge basis

ZEN MEMO No. 62 – 2025

Håvard Bergsdal | SINTEF Community

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Keywords: Ventilation systems, embodied emissions, data availability

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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, AFRY, Asplan Viak, Multiconsult, Civitas, FutureBuilt, Heidelberg Materials, Skanska, GK, NTE, Smart Grid Services Cluster, Statkraft Varme, Renewables Norway and Norsk Fjernvarme.

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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Abstract

As modern buildings become more energy efficient and more advanced in terms of integrated technical systems, the embodied emissions in these systems are receiving more attention. A recent advancement is the emergence, both within FME ZEN and other national research initiatives, of generic and comprehensive data sets for embodied emissions in ventilation systems, for which there has been a general lack, hindering a full understanding of their contribution to total building emissions. Initial studies applying the new databases indicate that the contribution from ventilation systems to building construction emissions is in the range of 5-10%, and likely higher when accounting for replacement and lifetime emissions. The contribution to lifetime emissions is heavily dependent on lifetime assumptions for components and ventilation systems, for which there is very little empirical evidence. The main part of the embodied emissions is found to be related to ductwork and air handling units. With increased attention to environmental impacts in general, the industry itself expects a significant increase in the number of available product EPDs (Environmental Product Declarations) both as a response to market expectations and as a proactive measure for expected legislation.

Content

Background

The recent decades have seen increasing awareness and understanding of emissions and environmental impacts related to the built environment. While early measures focused on increasing energy efficiency and thereby reducing energy use and emissions associated with operation and use of the buildings, more emphasis has later been put on quantifying, understanding, and reducing the embodied emissions from material production and use. One implication of the improved energy efficiency of modern and low-energy houses is that the relative importance of operational energy use emissions is reduced when considering lifetime emissions. Contributing further to this effect is the increased material use associated with energy efficiency improvements. In addition, modern energy-efficient new buildings commonly have more technical installations than before, where controlled and automated ventilation systems are part of these technical systems.

While embodied emissions in building materials are well researched and described the role of embodied emissions in technical systems has received much less attention, including for building ventilation systems [1]. Life Cycle Assessment (LCA) information for ventilation systems is generally scarce and with low precision. In LCA studies at the building level, ventilation systems are often based on Life Cycle Inventories (LCI) that include only a very limited set of components and dimensions, thus reducing precision, on reference values from other studies or in some cases a simple "emissions penalty" in lack of relevant data. Common LCA databases also have a very limited set of inventories for ventilation component types and dimensions. However, some studies present a quite detailed inventory for the ventilation system. These usually concern specific case buildings, and while the quality of the data might be good, its applicability and relevance for use in other studies are not validated.

The insufficient data on embodied emissions from ventilation and other technical systems can be partly explained by a diversity of components and variations, layouts and technological developments which makes standardization and relevance of data challenging. Professional organizations like CIBSE (Chartered Institution of Building Service Engineers) have also pointed to the complexity of the systems as a reason for a general lack of data on embodied emissions and Environmental Product Declarations (EPDs) [2]. However, results from various studies indicate that embodied emissions from ventilation and other technical installations can have a significant contribution to total building emissions. The ventilation system is the most material-intensive building service system and, in many cases, also the most energy-consuming. In order to start filling the knowledge gap and understand the contribution from ventilation systems to total building-related emissions it has within FME ZEN been developed a comprehensive LCI library for ventilation components. The library builds on previous work within FME ZEB and is documented and explained in [3].

Embodied emissions in ventilation systems

Even if the coverage and precision in LCA information for ventilation systems have been limited, new research reinforces the argument that their contribution to embodied building emissions is not negligible and therefore should be accounted for. There seems to be a trend that studies with a more comprehensive approach to including ventilation systems and higher resolution in terms of components and dimensions find a larger footprint and contribution from these systems to the overall embodied building emissions

[1]. This is further supported by findings from what currently seems to be the most comprehensive dataset libraries or databases for ventilation components.

Embodied climate emissions at construction stage

As mentioned, a library of datasets for ventilation components has been developed within FME ZEN [3]. This library aims to offer a set of generic component descriptions that can be used for design and evaluation of typical modern ventilation systems generally and without being developed for one specific case building. However, the ZEN ventilation library has been tested on a modern energy-efficient office building with gross floor area of 2 998 m^2, and results show an estimated 22.7 kg CO_2-eq/m^2 in embodied emissions from the ventilation system for the construction stage. A full evaluation of embodied emission for the construction of the building is not available, but empirical data indicated the contribution from the ventilation system to be less than 10%.

In another Norwegian research project called “Grønn VVS[1]”, Multiconsult is carrying out a similar effort to ZEN together with partners from industry. However, the scope of the project is more comprehensive, comprising heating, water and sanitation (VVS), and not only ventilation systems. Furthermore, the project aims to implement the LCA datasets directly in Revit to allow for early and automatic calculation of results. Both projects have in common the objective of providing better information and evaluation of emissions embodied in technical systems. Multiconsult is also a partner in FME ZEN and has used the LCA database developed in Grønn VVS to assess two case buildings in FME ZEN [4]. The case buildings are a school and a kindergarten from the Ydalir pilot project which is part of FME ZEN. The buildings have a gross floor area of 6 007 m^2 and 1 732 m^2, respectively. Embodied climate emissions related to the ventilation system from construction of the school are estimated to 13.7 kg CO_2-eq/m^2 and 7.1% of total embodied emissions for the full building construction. For the kindergarten the estimated embodied emissions from the ventilation system are 18.4 kg CO_2-eq/m^2. The share of total embodied construction emissions is not available for the kindergarten.

Both the results for the office building used as a case for the ZEN database and for the school using the Grønn VVS database are in the same range when it comes to share of construction related embodied emissions, while the embodied emissions per floor area is significantly lower for the school building.

Embodied climate emissions from replacement

Buildings have long lifetimes and, in many cases, exceed those of technical systems and components. This means that some components will need to be replaced one or more times during the building lifetime. The effect of this is to increase the embodied emissions, and possibly also the importance of ventilation systems and other technical installations. The case study for the school and kindergarten buildings at Ydalir estimates the embodied climate emissions from replacement to be higher than the initial emissions associated with the construction phase when considering a calculation lifetime of 60 years. For the school building the emissions from replacements are 33% higher than for the initial installation, and 40% higher for the kindergarten.

While embodied emissions from replacements appear to be very important in a lifetime perspective, their magnitude and importance rest on lifetime estimates that are inherently uncertain. Lifetime estimates are often generic and the empirical information scarce and of questionable reliability.

[1] https://www.multiconsult.no/gronn-vvs-skal-halvere-utslippene-fra-vvs-anlegg/

Environmental Product Declarations (EPDs) provide estimates, but these are usually not based on solid empirical data. This is supported from both literature and discussions with industry [5]. Compounding the problem is the definition of lifetime, which can vary besides the commonly used technical lifetime that describes the time until a component is worn out and not able to adequately fulfil its intended function. Other examples are functional lifetime which can be shorter than the technical lifetime if public regulations or user demands become stricter or change. Economic lifetime and aesthetic lifetime are additional examples [6]. Functional lifetime is highly relevant for rented commercial buildings where building layout and arrangements can change depending on the needs of the tenants.

The lifetime uncertainty and importance for total building lifetime emissions are discussed and presented in a separate memo from FME ZEN [7]. In this memo the impact of lifetime assumptions tested for the office building described in [3], and using the same ZEN LCA ventilation database. Similar to the results for Ydalir, replacement of ventilation components through a 60-year period has higher embodied emissions than the initial installation, the increase being 47%. However, through simple lifetime variations the embodied emissions are found to be 252% higher than initial installation when assuming a short lifetime and only 43% of initial emissions when assuming a long lifetime. Determining the correct lifetime to use for different components is complicated, but a clear finding from both studies is that replacement of components is certainly important for lifetime building emissions, and therefore needs to be considered, and that lifetime assumption is a critical parameter to understand, and its associated uncertainties communicated when presenting results.

Key contributors to embodied emissions

Ventilation systems consist of a range of different components. Two types generally show up as the most important in terms of embodied emissions. In the case study using the ZEN ventilation database, air handling units and circular ducts are the two contributors with almost equal shares and together accounting for 55% of total embodied emissions from the construction phase. In addition, comes different types of bends and connections that are part of the ventilation ductwork. Similarly, the case buildings from Ydalir show the same two components as top contributors.

However, the two component types have quite different characteristics. Whereas the ducts are simple and uncomplicated components consisting mainly of galvanised steel, the air handling units are the most complex and diverse in terms of material composition. They also require more maintenance and typically have a shorter estimated technical lifetime. It is not unreasonable to assume that ducts might be able to last for the full lifetime of the building with relatively simple cleaning operations. The more complex air handling units might also extend their lifetime by careful maintenance schemes but are still likely to need partial or full replacement during the building's lifetime. Considering the increasing attention and requirement for circularity, the potential for modularity and partial replacement should be considered by manufacturers of air handling and other more complex components.

Data availability and use

As previously mentioned, the availability of reliable and representative LCA data have been limited. Even widely used LCA databases, like Ecoinvent and others, have only included a few datasets for ventilation systems and components. The selection is highly limited in terms of both component types and dimensions. These limited datasets are only relevant for use in screening LCAs where precision is low, uncertainty high and the main objective is to simply get an idea of the magnitude of contributions from different building materials and components. The more detailed studies with higher precision datasets have commonly been highly case-specific and less adapted for use in other studies. For the purpose of using LCA information to systematically reduce embodied emissions during design and planning, high-resolution datasets need to be available to correctly address the effects of choosing different ventilation layouts.

However, as more attention is currently being paid also to technical systems and embodied emissions in products and services in general, the availability of data is improving and can be expected to do so considerably in the coming years. One thing is the emergence of databases like the ZEN database and Grønn VVS, but also the availability of the information on which they rely will become more complete and with better documentation, and more specifically in the form of EPDs. This is a general trend but is also confirmed by consultations with industry and manufacturers of ventilation components [5]. More manufacturers can be expected to develop EPDs for their products and for more component types than what is available today. This will contribute to increased consistency in the datasets since EPD procedures are standardized, and to more precise and representative assessments as more components, dimensions and manufacture designs will be represented and fewer missing datasets will need to be estimated in lack of specific information.

Increasing attention to embodied emissions is seen also internationally and from the industry itself. International professional engineering associations like CIBSE[2] and ASHRAE[3] both have their own initiatives to promote awareness and provide data and knowledge about this topic. In response to the need for more informed decisions regarding embodied emissions and a simultaneous general lack of EPDs, or related documentation for technical building systems, CIBSE has introduced a methodology termed TM65 to provide guidance on the compilation of data on embodied emissions in technical components [2]. The methodology and corresponding calculations are not EPDs but are intended to provide basic information on conservative levels of embodied emissions for products still lacking specific EPDs. The methodology and database are not supposed to supplant EPDs or compete in terms of precision, but rather present a practical approach to filling data gaps where EPDs have not yet been developed. Calculations for different components are compiled in a database accessible to members of the organization.

The American ASHRAE organization has also acknowledged the need for improved information on embodied emissions in buildings, and for technical systems in particular. ASHRAE has proposed a joint standard for the evaluation and documentation of greenhouse gases for buildings [8].

More and better datasets will enable further use and more studies to be carried out with higher quality. However, more importantly, evaluation of ventilation systems can also be more fully implemented in environmental decision support tools covering different stages in the design process from early screening to final optimisation layout. Today's tools for environmental assessment of buildings have at best very generic data giving a crude estimate for ventilation and other technical installations. More detailed assessments are usually carried out by transferring data between different tools or software, involving significant time-consuming manual work. One example of this is the assessment of the case building used in the documentation of the ZEN ventilation library [3]. For this work a list of ventilation

[2] CIBSE - Chartered Institution of Building Services Engineers
[3] Home | ashrae.org

components was first extracted from the building's BIM model (Building Information Modelling), followed by manual matching of datasets available in the ZEN ventilation database. Missing components were estimated or represented by proxies. The assessment was then carried out in a dedicated LCA software (SimaPro) for evaluation of results. Both steps are time-consuming, and in particular, the matching process which also requires sufficient knowledge about ventilation components and design. Such a process is not likely to be carried out several times, thereby limiting its use for structured evaluation and optimization through a design process from early project concept to as-built documentation.

Ensuring that the appropriate information is available through the different steps in the design and building process should be the key objective for providing data. Any good evaluation tool will rely on good quality data, but for the most efficient use, they need to be implemented in tools that can follow the whole design process and make use of the same data to ensure consistency along the different design phases of a building. In the Grønn VVS project, the database has been implemented in the Revit BIM tool, which enables more rapid and integrated calculations.

Even when LCA databases are integrated with BIM tools there is still a need for matching the resolution in data with the information available at every step of the design process. In early stage design the exact layout, components, and dimensions may not be decided, while EPD-based information describes specific components. This means that for the early stages, some type of references, typical or average values need to be developed. Such values can be developed from the available databases. In the longer term, empirical values could also be used, but that requires sufficient projects to draw data from.

Current building regulations require environmental assessment of new buildings but do not include the various technical installations such as ventilation systems. Improved information from database initiatives and increasing availability of EPDs will provide the foundation for setting requirements also for technical installations. A first step towards this could be to require that ventilation systems should be included in the necessary documentation, and later followed by quantitative thresholds to be met. The latter would be possible to implement as more empirical knowledge would be gained from the first step.

Structured and optimised emissions reductions

The full potential for reduced emissions from ventilation systems can only be fulfilled by a structured and consistent approach that encompasses the full planning process from early design concepts through detailed systems layout and final selection of component suppliers. Decisions taken in the earlier stages of concept and design will inherently constrain the solution space for the later detailing of system layout and component types. As with measures for reducing emissions related to other parts of the building, the most efficient solutions are found when planning for emissions reductions from the start.

As previously described, there is very limited information and experience from past studies of environmental impacts from ventilation systems. The generally increased attention to ventilation and other technical systems, and the increased availability of both generic datasets for component types and available product EPDs, should facilitate development of reference values or intervals for different ventilation concepts and different building types. The purpose of this would be to allow for early guidance for evaluation of different ventilation concepts and to provide an early screening of proposed alternatives by having reference values to use as benchmarks. Furthermore, it would provide a starting point for optimisation of the layout throughout the design and detailed planning process and provide a reference point for measuring the emissions reductions achieved during planning.

However, optimisation to reduce embodied emissions in materials can lead to sub-optimisation if not seen in relation to energy use and associated emissions from electricity production and supply. A simplistic optimisation with respect only to embodied emissions might lead to a simple conclusion of downscaling the dimensions of the ductwork as much as possible while still meeting the requirements for indoor air quality. However, reduced cross sections in the ductwork will imply higher energy use for pushing the air through, while larger diameters will do the opposite but also entail higher embodied emissions. Effects on the resulting operational energy use will endure for the lifetime of the building, provided no extensive restructuring is assumed, and thereby have a significant effect on the total building-related emissions. An optimisation model to specifically address this issue has been developed within FME ZEN and is documented in a journal article currently pending publication [9]. Even if the relationship between embodied and operational emissions is important, a major obstacle to assessing this trade-off is that it inevitably rests on the assumption of electricity mix and its trajectory for the building lifetime. In a similar way, embodied emissions related to future component replacement also carry uncertainties as the emission profiles for component manufacturing several decades into the future are equally difficult to assess. However, even if emissions levels are uncertain, one can still identify at which points in the selection of dimensions the corresponding change in energy use will be bigger or smaller, which will by itself provide an important indication of where the trade-offs are.

In assessing the embodied emissions from ventilation components, there will be uncertainties also related to component design and manufacturer, especially for the more complex components. The preferred alternative for early-stage planning would be to apply average values for types of components, but until a sufficient supply of manufacturer-specific EPDs are available, the more practical approach would be to aim for using example products that are considered typical and representative for a majority of the market.

Conclusions

There is currently an on-going change in the attention to and knowledge about embodied emissions in technical systems in buildings, including ventilation systems. Both nationally and internationally, new initiatives are initiated to improve the knowledge about their importance in the overall environmental footprint of buildings, and in how to make relevant data available and implemented in tools for planning and design. At the same time the number of available EPDs is increasing, and the industry expects this trend to accelerate further.

While studies on the emissions related to material use in ventilation systems have been few and with relatively low potential for wider use, recent years have seen new initiatives for more generic and complete datasets and databases that allow for generic use in different types of buildings. Early studies based on these suggest that ventilation systems represent a significant part of embodied emissions in buildings, and particularly when considering the replacement of components during the building lifetime. When designing and planning ventilation systems, systematic assessment of impacts should be included from early concept evaluation to final layout and ultimately choice of supplier. Furthermore, when optimising the ventilation system in terms of reduced emissions, the trade-off between material use-related and operational emissions should not be omitted.

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