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Note

Project: Airmaster

Subject: LCA of ventilation systems

1 Purpose and summary of results

The purpose of the present study is to compare respectively a decentralized and a centralized ventilation system on a specific case from an environmental perspective. The environmental impact is evaluated on the basis of the total CO_2 emission from the two ventilation systems and is furthermore compared to the CO_2 emission from a reference building.

The study is based on a building section at Ellemarkskolen in Køge, Denmark, where decentralized Airmaster units have been installed in 31 classrooms during refurbishment. As an alternative to this, a traditional centralized ventilation system is constructed. This system includes a central VAV unit, ventilation ducts, diffusers, dampers, silencers etc. For both ventilation systems, the total material quantities have been calculated and specific material quantities for two decentralized units, respectively an AM1000 and an AM500 from Airmaster, as well as a central VAV unit have been obtained.

For the assessment of the environmental impact of the two ventilation systems, generic material datasets from the German Ökobau database have been used. This means, that the results of the present study are not product-specific, but a general consideration of two ventilation principles with the stated material quantities.

The study shows that for a 25 year-period, the total CO_2 emission for a decentralized ventilation system (without diffusers) including operating energy is 45% lower than a centralized VAV system. The CO_2 emission from the decentralized system is exclusively caused by the units, intake and outlet through the exterior wall as well as electricity consumption for operation and heating, whereas the centralized system in addition has contributions from ducts, dampers, diffusers and district heating.

If the two ventilation systems are considered in relation to an entire building, the study shows that the central ventilation system incl. operational energy accounts for 17-18% of the total CO_2 emission, while the decentralized system only account for 10-12%.

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2 Delimitation of life cycle assessments

The following sections present the results of four life cycle assessments, which are based on specific material quantities for a centralized VAV unit and two decentralized ventilation units from Airmaster. Despite this, the environmental impact calculated in this study, cannot be considered as an environmental declaration of the air handling units, as the calculations are performed on the basis of generic material datasets from the German database Ökobau (data accessed April 2020), and not specific material data for the actual used materials.

Hereby, the study exclusively presents an assessment for ventilation systems accounting for the same amount of material as for the studied, and results and figures presented in the section about environmental impact therefore only serve the purpose of showing the significance of calculating the environmental impact of installations in buildings more detailed.

3 Life cycle assessments in a Danish context

For several years, life cycle assessments (LCA) have been the most efficient method of assessing the overall environmental impact of a product or a building throughout an entire life cycle. For this reason, the method is internationally recognized and in the recent years, it has found its way into various certification systems and building regulations.

In Denmark, LCA is a part of the certification system DGNB, which is managed by Green Building Council. As a part of this system, LCA is used as a substantial tool for reducing the environmental impact of buildings as well as the consumption of non-renewable resources. The result of the LCA accounts for a maximum of 10.5% of the total DGNB score and requires, among other things, that an LCA is performed in the early design stage and that the used data is as specific as possible. Hence, in the newest version of DGNB, which will be published later in 2020, the data quality is considered by multiplying the final results of the LCA by a factor depending on the quality. If generic material datasets are used, the environmental impact must be multiplied by a factor of 1.5. If industry EPD's are used, the factor is 1.2, while calculations with product specific EPD's can be used with a factor of 1.0

The implementation of this method has a huge impact of the overall LCA result and herby the overall DGNB score. Therefore, it is important to develop the number of available product specific EPD's further.

Besides being a part of the DGNB system, LCA is also included in one of nine requirements in a new Danish voluntary sustainability class for buildings (Frivillig Bæredygtighedsklasse). In two years, this will be included as a part of the national building regulations, hence introducing specific requirements to the total CO_2 emission from buildings including operational energy.

4 Environmental impact assessment

In the following sections, calculation prerequisites for the environmental assessments of the two ventilation systems are listed.

4.1 Calculation prerequisites

The prerequisites determined in the Danish voluntary sustainability class[1] and the calculation software LCAbyg[2], developed by the Danish Building Research Institute, are applied for the present environmental impact assessment. Normally a service life of 50 years is used in an assessment at building level, however on a product level, it is difficult to determine the future and how the production of the product will possibly change. Therefore, the service life in the present assessments are set to 25 years, which is the average lifetime of an air handling unit in new buildings[3]

As described earlier, the assessments are based on generic material datasets from the German database Ökobau[4] (data accessed April 2020).

As shown in figure 1, the assessments include the following life cycle stages; the production stages A1-A3, the construction process stages A4-A5, the use stage B6 and the end of life (EOL) stages C3-C4. The results are only evaluated in terms of global warming potential expressed as CO_2 equivalents and stated in the unit kg CO_2eq/m² yr.

Transport from the production site to the building site is measured in the construction stage A4. However, as the assessment is not considering a specific VAV unit with a known production site, all materials are assumed to be transported by lorry and for an average distance of 500 km[5]. The CO_2 emission for this kind of transport is presumed to be 0.725 kg CO_2eq/km as stated by the Danish Energy Agency[6].

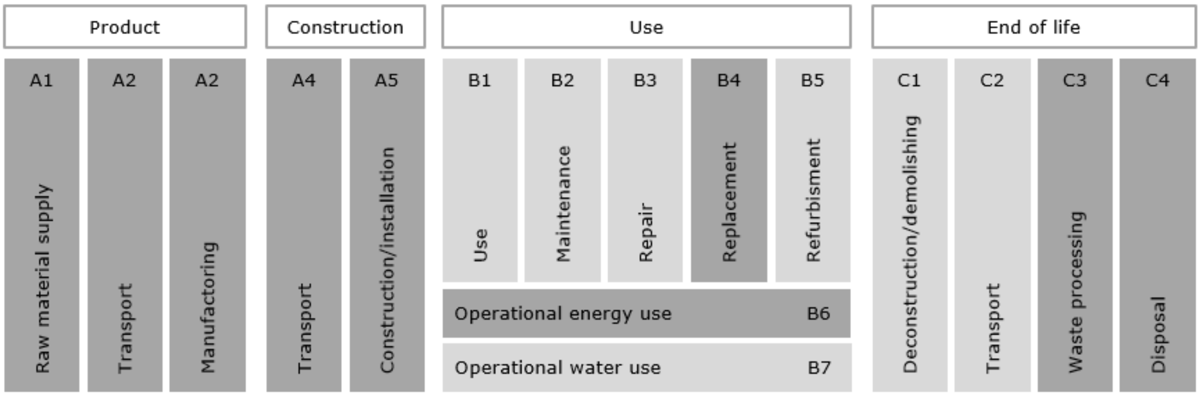


Figure 1. Included life cycle stages according to the Danish voluntary sustainability class marked with dark grey (As no materials has a lifetime shorter than the service life, B4 is not relevant).

[1] https://baeredygtighedsklasse.dk/
[2] https://www.lcabyg.dk/
[3] https://sbi.dk/Assets/Levetider-af-bygningsdele-ved-vurdering-af-baeredygtighed-og-totaloekonomi/sbi-2013-30-rapport.pdf
[4] https://www.oekobaudat.de/
[5] https://baeredygtighedsklasse.dk/5-Krav-og-vejledning/Bilag-til-krav-om-livscyklusvurdering#bilag-1-emissionsfaktorer
[6] https://ens.dk/sites/ens.dk/files/Analyser/emissionsfaktorer_for_vejtransporten_pr._km.pdf

Normally the construction stage A5 includes the energy consumption during the construction work as well as transport on site and waste of building materials. As the refurbishment of the 31 class-rooms is conducted prior to the present study, no data is collected during this process, A5 is therefore left out of the assessment. A waste of 10% on all building materials except the air handling units is however included according to the Danish voluntary sustainability class.

For the use stage B6, an extrapolation of the emission factors for Danish electricity and district heating is applied according to the Danish Transport, Construction and Housing Authority[7]. The extrapolation is visualized in figure 2 and illustrates how the Danish energy mix is assumed to develop in the future.

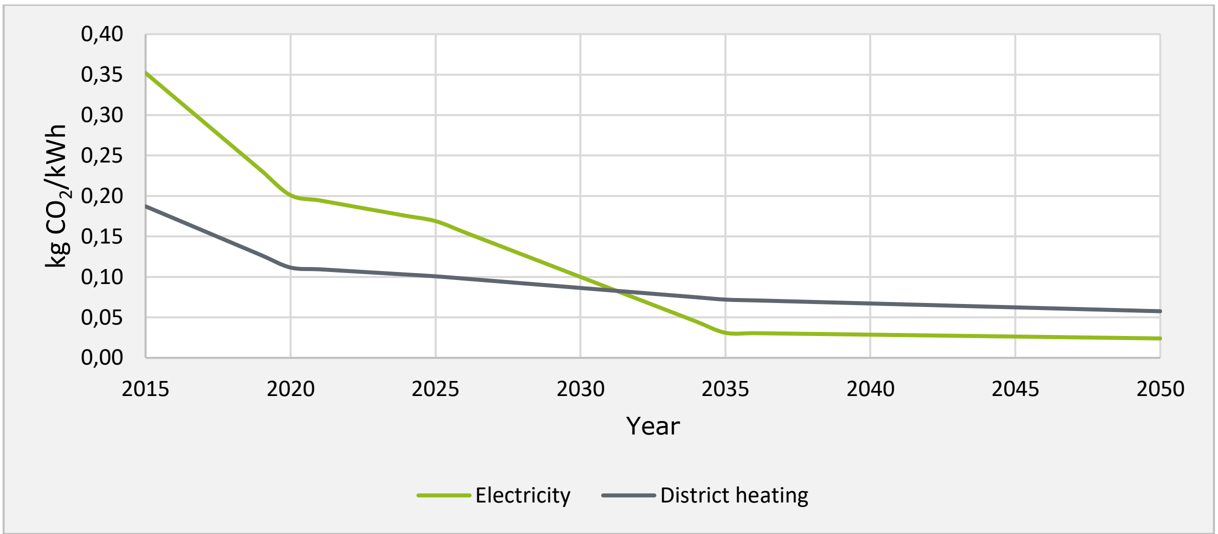


Figure 2. Extrapolation of Danish emission factors 2015-2050

In order to be able to compare different types of energy, the supplied energy for operating the air handling units is converted to supplied primary energy by the primary energy factors as described in the Danish Building Regulations. The primary energy factor for electricity is 1.9 and 0.85 for district heating.

At last, to illustrate the share of ventilation in relation to an entire building, environmental data for a reference building is obtained. Table 1 represents the environmental impact for building materials and operational energy of a reference building without ventilation. The data are an average of 22 DGNB certified office buildings and are assumed representative for the examined building section of 2630 m².

Table 1. CO_2 emission pr. m² pr. year for a reference building without ventilation

Building	Materials	Heating	Electricity
Reference building	6.9 kg CO_2/m² yr	1.4 kg CO_2/m² yr	0.05 kg CO_2/m² yr

4.2 Decentralized ventilation system

The decentralized ventilation system consists of the decentralized units AM1000 and AM500. The material quantities for these units are provided by Airmaster and are listed in table 2 and 3 together with the expected lifetime of each material.

[7] https://www.trafikstyrelsen.dk/da/-/media/TBST-DA/Byggeri/B%C3%A6redygtigt-byggeri/Om-b%C3%A6redygtigt-byggeri/Livcyklusvurdering-LCA/Nye-emissionsfaktorer-for-el-og-fjernvarme.pdf

In the assessment, a total amount of 30 AM1000 units and 1 AM500 unit is included for the 31 classrooms. The studied classrooms are shown on a floorplan in appendix A.

Table 2. Material quantities and lifetimes for an AM1000 unit

Material	Amount	Lifetime	Replacements
Aluminium	26.2 kg	25 years	0
Galvanized steel	256.9 kg	25 years	0
Plastic	5.2 kg	25 years	0
Insulation	7.0 kg	25 years	0
Glue/silicone	3.0 kg	25 years	0
Electronics	2.2 kg	25 years	0
Filter	1.0 kg	-	-
Total	301.5 kg		

Table 3. Material quantities and lifetimes for an AM500 unit

Material	Amount	Lifetime	Replacements
Aluminium	9.5 kg	25 years	0
Galvanized steel	74.6 kg	25 years	0
Plastic	1.0 kg	25 years	0
Insulation	9.1 kg	25 years	0
Glue/silicone	7.8 kg	25 years	0
Electronics	2.0 kg	25 years	0
Filter	3.2 kg	25 years	0
Total	0.8 kg	-	-
Total	108 kg		

As it has not been possible to obtain quantities for filters for the central VAV unit, the environmental impact related to this is however not considered.

In addition to the unit itself, each Airmaster comes with 80 cm duct for intake and outlet through the exterior wall. The diameter of the duct is 315 mm for the AM1000 unit and 250 mm for the AM500 unit.

Table 4. Material quantity and lifetime of ducts for intake and outlet

Ventilation component	Material	Total amount	Lifetime	Replacements
Ducts	Sheet metal	134.9 kg	25 years	0

By default, the units are installed directly in each classroom, but as an alternative to this default solution a scenario with diffusers for both supply and extract is examined as well. Material quantities and life times for this scenario are listed in table 5 and 6 and must be added to the material quantities in table 2-4.

Table 5. Additional materials for the alternative decentralized ventilation system

Ventilation component	Description	Total amount	Weight pr. unit
Distribution - Ducts - Fixing clamps	 Variable size depending on air flow Fixing pr. 2.5 m in average	 589 m 279 pcs.	 4.8 kg/m. 0.5 kg/pc.
Classrooms with AM1000 - Supply diffusers - Extract diffusers	30 classrooms 4 pc. pr. room 2 pc. pr. room	 120 pcs. 60 pcs.	 2.8 kg/pc. 2.8 kg/pc.
Classroom with AM500 - Supply diffusers - Extract diffusers	1 classroom 2 pc. pr. room 1 pc. pr. room	 2 pcs. 1 pc.	 2.8 kg/pc. 2.8 kg/pc.

Table 6. Material quantities and lifetimes for alternative decentralized ventilation system

Ventilation component	Material	Total amount	Life time	Replacements
Ducts	Sheet metal	2 827 kg	25 years	0
Diffusers	Galvanized steel	512 kg	25 years	0
Fixing clamps	Steel	140 kg	25 years	0

The energy consumption for the decentralized ventilation system is estimated by Airmaster and is listed in table 7, both as supplied energy and supplied primary energy. The working time is 8.00-16.00 and the units are assumed to run 200 days a year with an average air flow of 89% of max.

Table 7. Energy consumption for the decentralized ventilation system

Energy consumption	SFP/ heat recovery	Sup. energy [kWh/yr]	Sup. energy [kWh/m² yr]	Sup. primary energy [kWh/m² yr]
Electricity for operation - AM1000 - AM500	 0.612 kJ/m³ 0.565 kJ/m³	6 967	2.65	5.04
Electricity for heating - AM1000 - AM500	 83.2% 83.8%	3 097	1.18	2.24
Total		10 064	3.83	7.28

The energy consumption listed in table 7 is also applied for the alternative decentralized system, where diffusers are included in the assessment.

4.3 Centralized ventilation system

For comparison of the decentralized ventilation system, a fictitious centralized VAV system is constructed. As the studied primary school is build in the late 1960s, the building is not necessarily suitable for a centralized VAV system with large distribution ducts. Therefore, two different scenarios are considered. One scenario, where the air handling unit and the distribution ducts are installed on the warm side of the building envelope, and one scenario, where the air handling unit and the distribution ducts are installed on the cold side of the building envelope (on the roof). In addition, the studied classrooms are uneven distributed, why a more even distribution of the rooms are assumed for the fictitious centralized ventilation system. Gross area and the number of classrooms is however maintained. The distribution of classrooms is sketched in appendix B.

Table 7 describes the presumed composition of the centralized VAV system.

Table 7. Composition of the centralized VAV system

Ventilation component	**Description**	**Total amount**	**Weight pr. unit**
Technical room			
- VAV-unit	Air flow 29 000 m³/h	1 pc.	3 529 kg/pc.
Distribution			
- Ducts	Variable size depending on air flow	1 250 m	7.5 kg/m.
- Fixing clamps	Fixing pr. 2.5 m in average	557 pcs.	0.5 kg/pc.
- Fire dampers	5 fire sections, 1 damper pr. section	5 pcs.	6.4 kg/pc.
- *Insulation*	*100 mm insulation on unit and exterior ducts**	*120 m³*	*27 kg/m³*
Large classrooms	30 classrooms		
- Supply diffusers	4 pcs. pr. room	120 pcs.	2.8 kg/pc.
- Extract diffusers	2 pcs. pr. room	60 pcs.	2.8 kg/pc.
- Plenum boxes	4 pcs. pr. room	120 pcs.	7.3 kg/pc.
- Dampers	1 pc. pr. room	30 pcs.	2.9 kg/pc.
- Silencers	2 pcs. pr. room	60 pcs.	11.9 kg/pc.
Small classrooms	1 classroom		
- Supply diffusers	2 pcs. pr. room	2 pcs.	2.8 kg/pc.
- Extract diffusers	1 pc. pr. room	1 pc.	2.8 kg/pc.
- Plenum boxes	2 pcs. pr. room	2 pc.	7.3 kg/pc.
- Dampers	1 pc. pr. room	1 pc.	2.9 kg/pc.
- Silencers	2 pcs. pr. room	2 pcs.	11.9 kg/pc.

**Applied only for the scenario where the air handling unit and ducts are installed on the cold side of the building envelope.*

Material quantities and lifetimes for the centralized VAV unit is listed in table 8. Quantities for the distribution system is listed in table 9.

Table 8. Material quantities and lifetimes for 1 pc. of centralized VAV unit 29 000 m³/h

Material	Amount	Lifetime	Replacements
Aluminium	343 kg	25 years	0
Cobber	20 kg	25 years	0
Mineral wool	239 kg	25 years	0
Galvanized steel	2 860 kg	25 years	0
Plastic	67 kg	25 years	0
Filter	-	-	-
Total	3 529 kg		

Table 9. Material quantities and lifetimes for distribution system

Ventilation component	Material	Total amount	Life time	Replacements
Ducts	Sheet metal	9 454 kg	25 years	0
*Insulation**	*Duct insulation*	*3 116 kg*	25 years	*0*
Diffusers	Galvanized steel	512 kg	25 years	0
Plenum box	Galvanized steel	891 kg	25 years	0
Dampers	Composite	31 pcs.	25 years	0
Silencers	Galvanized steel Mineral wool	662 kg 3.0 m³	25 years	0
Fire damper	Composite	5 pcs.	25 years	0
Fixing clamps	Steel	279 kg	25 years	0

**Applied only for the scenario where the air handling unit and ducts are installed on the cold side of the building envelope.*

The presumed energy consumption for the centralized ventilation system is listed in table 10. The same operational hours as for the decentralized ventilation system is assumed, meaning 8.00-16.00, 200 days a year and an average air flow of 89% of max.

The energy consumption for the scenario where the air handling unit and ducts are installed on the cold side of the building envelope is listed in table 11. This scenario has an increased consumption of district heating because of the heat loss from the ducts and the air handling unit.

Table 10. Energy consumption for centralized VAV system on warm side of the building envelope

Energy consumption	SFP/ heat recovery	Sup. energy [kWh/yr]	Sup. energy [kWh/m² yr]	Sup. primary energy [kWh/m² yr]
Electricity	1.74 kJ/m³	19 960	7.59	14.42
District heating	82.5%	3 226	1.23	1.05
Total				15.47

Table 11. Energy consumption for centralized VAV system on cold side of the building envelope

Energy consumption	SFP/ heat recovery	Sup. energy [kWh/yr]	Sup. energy [kWh/m² yr]	Sup. primary energy [kWh/m² yr]
Electricity	1.74 kJ/m³	19 960	7.59	14.42
District heating	82.5%	7 434	2.83	2.40
Total				16.82

4.4 Results

The results of the life cycle assessments with a calculation time of 25 years are presented in figure 3 and 4. The charts show that the total CO_2 emission for the decentralized ventilation system without diffusers but including operational energy is 0.88 CO_2/m^2 yr., while the emission is 1.07 CO_2/m^2 yr. if diffusers are included in the assessment. The emission for the centralized VAV systems installed on the warm side of the building envelope is 1.59 kg CO_2/m^2 yr. and 1.85 kg CO_2/m^2 yr. if the air handling unit and distribution ducts are installed on the cold side of the building envelope.

The decentralized system hereby emits 45% less CO_2 during a 25 year-period compared to the centralized VAV system without insulation, and 52% less than the system with insulated ducts and air handling unit.

If diffusers are included in the decentralized system the savings are reduced to respectively 33% and 42% compared to the two centralized systems.

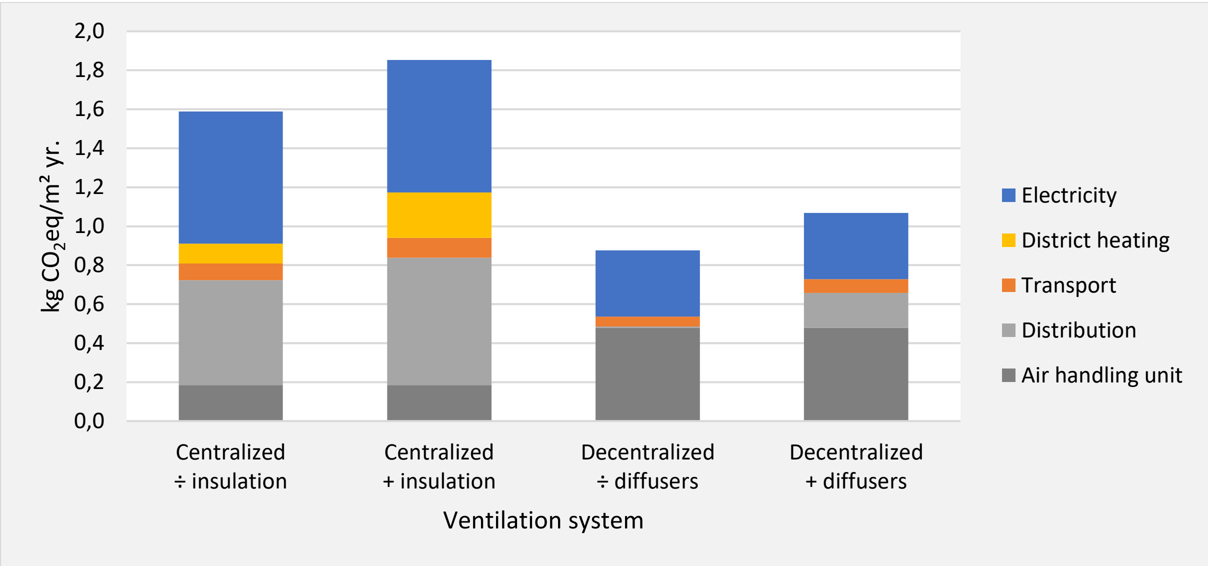
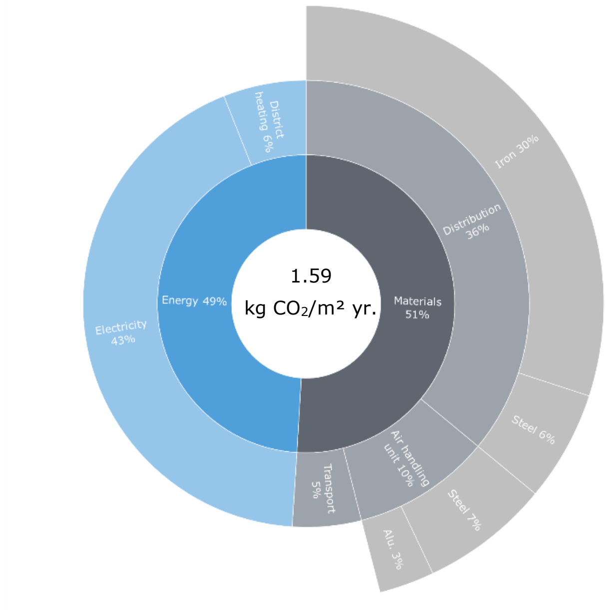


Figure 3. Total CO_2 emission for centralized and decentralized ventilation systems.

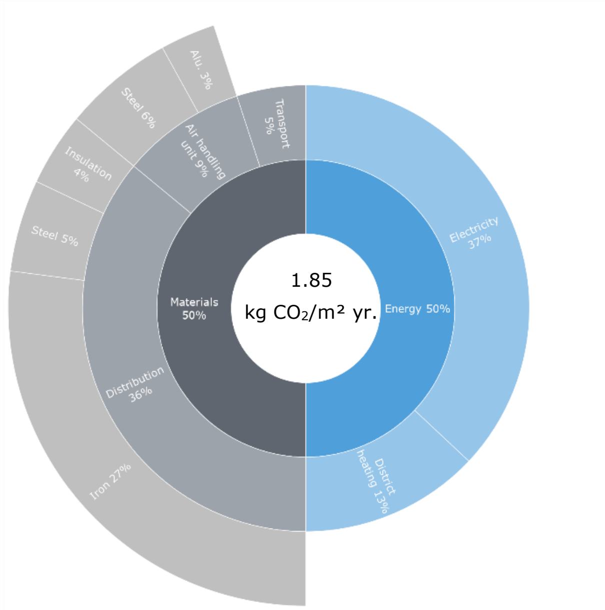
The CO_2 emission for the decentralized systems is mainly caused by the air handling units and the consumption of electricity for operation and heating, whereas the emission for the centralized systems additionally is caused by ducts, dampers, diffusers and district heating.

For the centralized VAV systems the operational energy consumption is responsible for 50% of the total CO_2 emission, while the share for the decentralized systems is between 32% and 39%. The reason for this difference is mainly because the centralized air handling unit has a higher SFP value and a lover heat recovery.

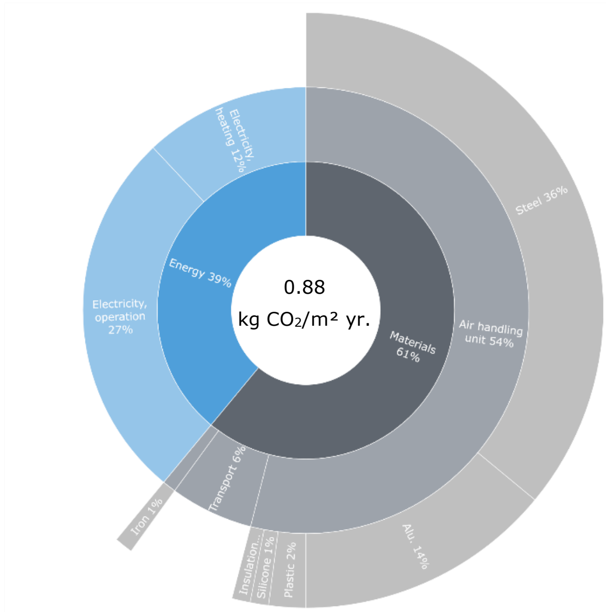
Figure 4 presents the distribution of the CO_2 emission for the four different ventilation systems.



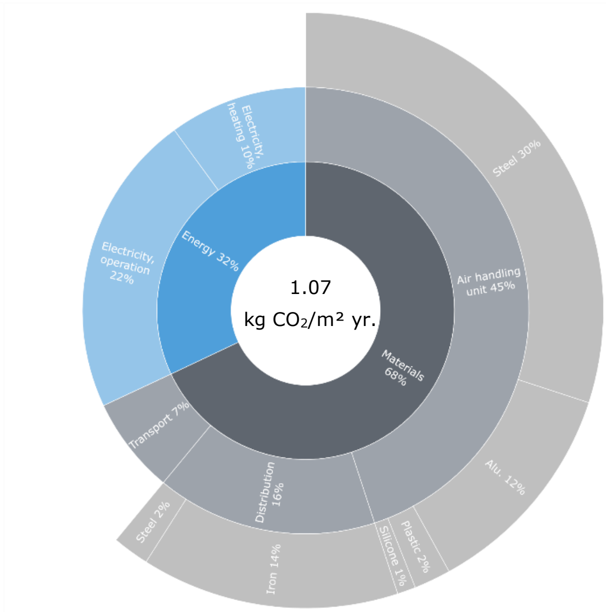
Centralized ventilation system ÷ insulation



Centralized ventilation system + insulation



Decentralized ventilation system ÷ diffusers



Decentralized ventilation system + diffusers

Figure 4. Distribution of CO_2 emission for centralized (top) and decentralized ventilation systems (bottom).

If the air handling units are studied separately, the environmental impact for the 31 Airmaster units are more than 2.5 times the impact from a single centralized VAV unit. However, contrary to the centralized unit, the Airmaster units can be used without any further distribution fittings, which means that the environmental impact caused solely by the materials for the decentralized ventilation system in the end is 33% less than for the centralized system installed on the warm side of the building envelope.

Figure 5 presents the distribution of the total CO_2 emission for the air handling units divided between materials. As shown, aluminium and galvanized steel make up the largest share for both the centralized and decentralized units.

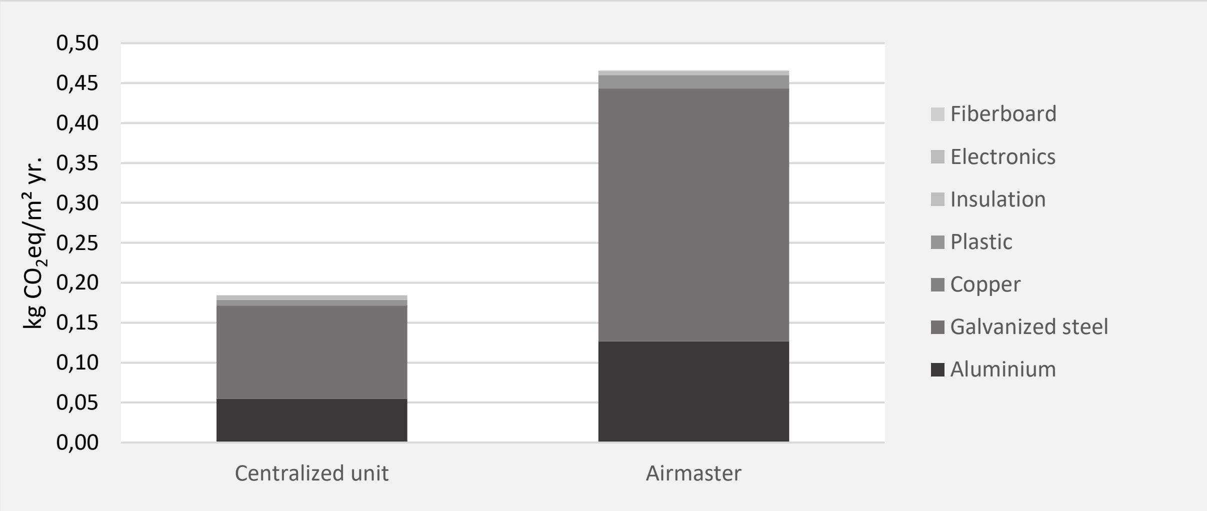


Figure 5. Total CO_2 emission for air handling units divided between materials.

Figure 6 shows the CO_2 emission for the ventilation systems in relation to a reference building excluding operational energy consumption. For a period of 25 years, the centralized ventilation systems account for 11-12% of the total emission from an entire building, whereas the decentralized ventilation systems accounts for 7-10%.

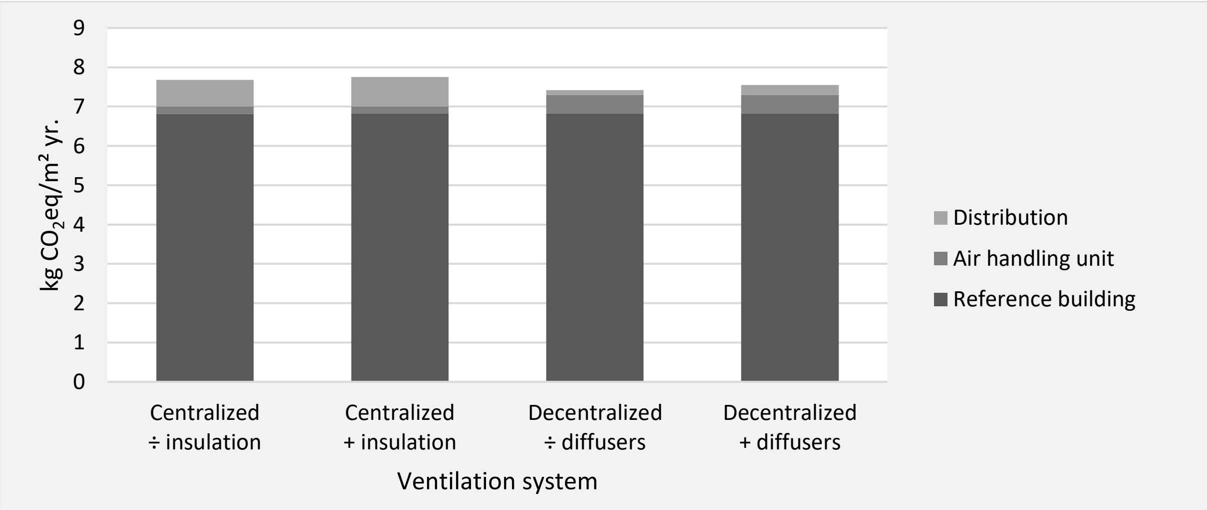


Figure 6. CO_2 emission for ventilation systems and reference building.

If the energy consumption for the rest of the reference building is included in the life cycle assessment, figure 7 shows, that the centralized ventilation systems including operational energy are responsible for 17-18% of the total CO_2 emission for the entire building, while it is only 10-12% for the decentralized ventilation systems.

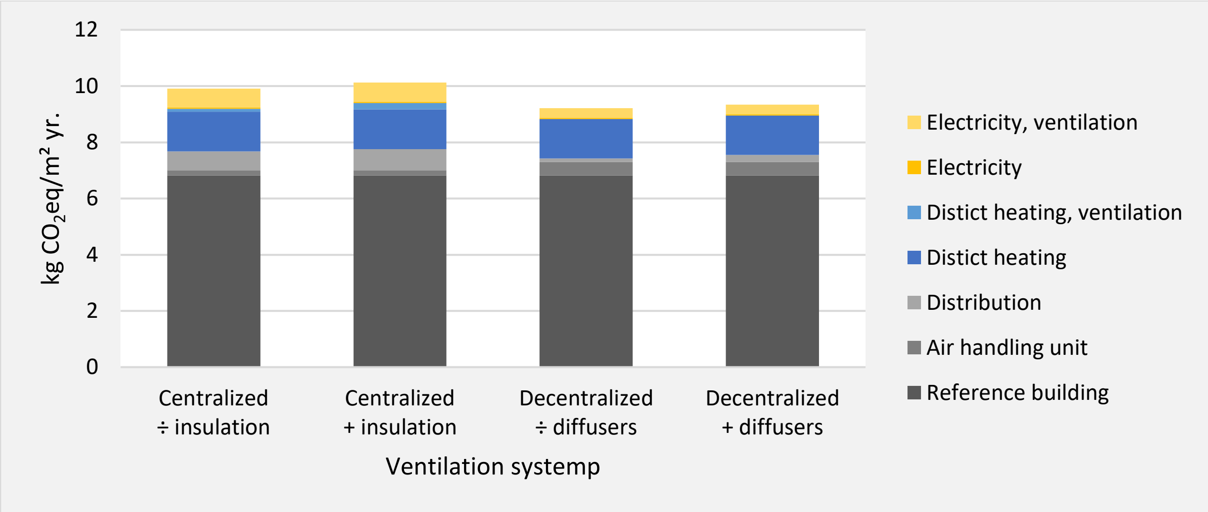


Figure 7. *CO_2 emission for ventilation systems, reference building and operation energy.*

5 Actual conditions

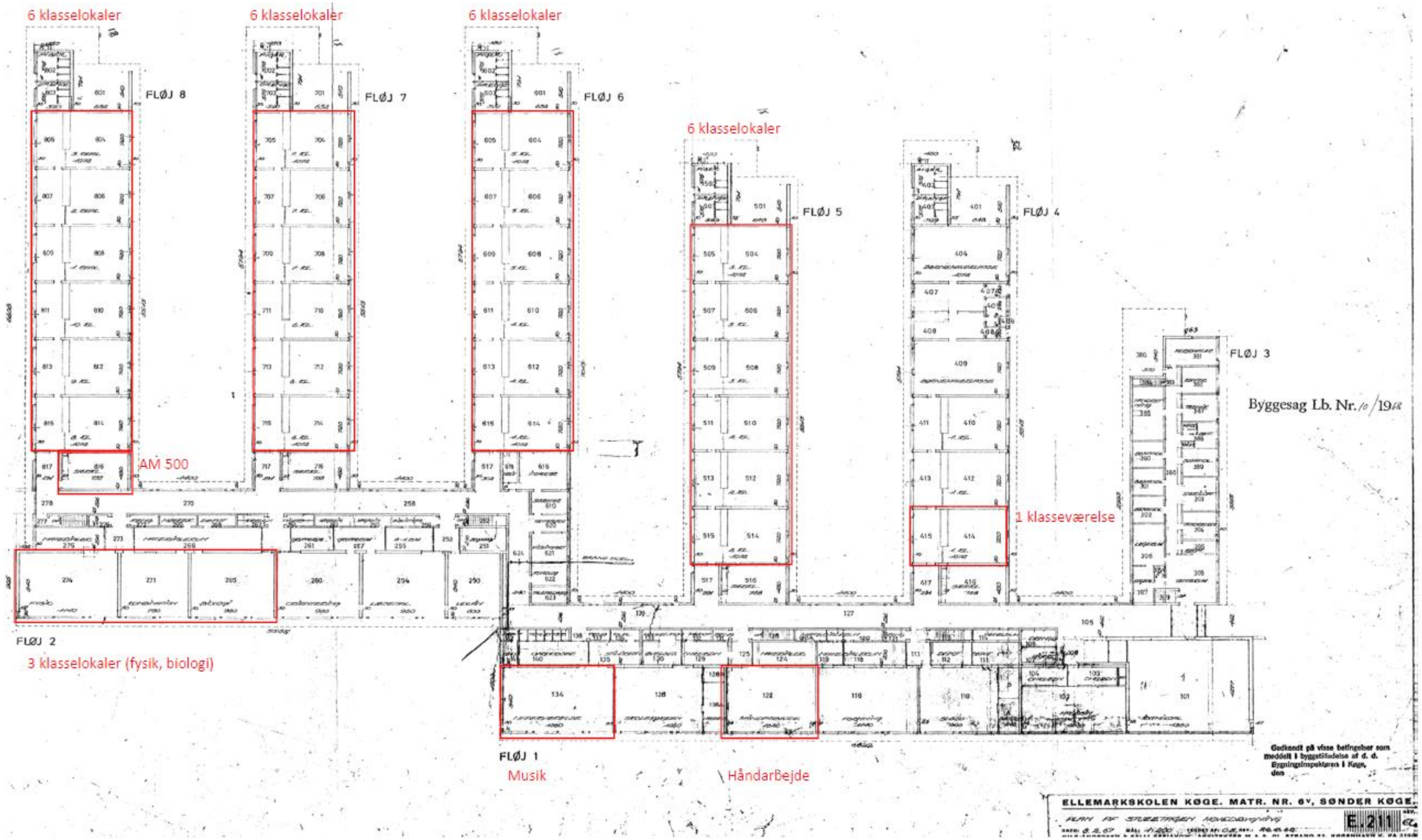
As described in the previous sections, the assessments in the present study is based on specific material quantities for two Airmaster units and one central VAV unit. During the study, MOE has obtained data for multiple VAV units from different brands, but as every single VAV unit has different composition and different materials, the findings in the study cannot be considered valid for all VAV units.

In continuation hereof, the calculated environmental impact for the different ventilation systems is based on generic material datasets, why the actual environmental impact may be different in reality. For example, there is a very big difference between what kind of steel is used, and thus, the CO_2 emission can vary by a factor of 4 depending on the production and use of recycled steel. To get an accurate picture of the actual environmental impact, it is necessary to make an EPD (Environmental Product Declaration) on each individual product.

Moreover, it has not been possible to obtain environmental data for the used insulation in the Airmaster units. The specific insulation is called "bonded foam" and is made out of recycled PUR insulation. Instead a generic dataset for mineral wool has been used, but since the CO_2 emission from the insulation account for only 1% of the total CO_2 emission, the results are not changed significantly.

Calculations and findings in the present study hereby cannot be generalized. They only show a trend and potential in calculating the environmental significance of the installations in our buildings more detailed.

Appendix A – Floorplan, decentralized ventilation system



Appendix B – Floorplan, centralized ventilation system