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Analysis of Swedish school buildings' energy performance certificates with focus on ventilation systems

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Abstract. Energy performance certificates are valuable sources of information about buildings. They are primarily used to assess the buildings' energy performance, however the data included can also be used for building stock description or analysis from different perspectives. School buildings account for a substantial part of the Swedish public building stock and represent a great opportunity for implementation of energy saving strategies. To improve the energy efficiency, it is first important to analyse and understand the current energy use and identify the key factors responsible for most of the energy use. In Sweden, data used for EPC compilation are in most cases real measured data opposite to other European countries where EPC comprises calculated data practices. Therefore, the energy performance value provides a much more realistic representation of the building energy use. This study analyses certain aspects of school buildings' energy performance using data available in EPCs, such as year of construction, floor area, heat supply systems and ventilation system. Comparison with data from some other European countries is also presented. The data which could be included in the certificate to extend the potential of EPC use in other areas, such as evaluation of indoor environmental quality, is also discussed.

1. Introduction

School buildings create a substantial part of the Swedish building stock. According to the Swedish Energy Agency report [1], the school buildings' heated floor area accounts for 27% of all non-residential buildings in Sweden, creating the highest share of all non-residential building types and presenting a great potential for implementing energy saving measures. Moreover, it accommodates an especially sensitive group of building users – children. They spend a substantial part of their days at school; therefore, the quality of the indoor environment is crucial to ensure their proper development and well-being.

The Energy performance certificate (EPC), first introduced by EPBD in 2002 [2], serves as a valuable source of information about building's energy efficiency, but they do not provide information about the indoor environment. Such complementary information was discussed in connection to the recast of the EPBD, but it seems that the focus is on "deep renovation" in ongoing projects to develop EPC [3]. However, their use can be much wider than originally intended. EPC databases present a unique compilation of data which can be used in many applications, beyond the mere energy assessment of buildings. A study reviewing existing application of EPCs [4] identified 13 problem domains of use, such as mapping building energy performance (EP), building energy retrofitting or investment analysis. This analysis also showed that a particularly large number of articles on EPCs come from three countries

– UK, Sweden, and Italy. According to the study, this can be explained by a possibility to access the EPC data as well as a high priority placed on the buildings' energy efficiency question.

In many EU countries, the EP value stated on the EPC is a calculated value based on the building's characteristics. The actual building performance however can differ to a high extent from such a calculated number [5], [6]. One of the significant factors leading to such differences is occupant behaviour, although the extent of its contribution is unknown [7]. The uniqueness of Swedish EPCs lies in the fact that the EP value is, in most cases, based on actual measured data collected during a period of one year. Therefore, the value provides a more realistic representation of the building energy use than the predicted value.

To describe the EP of a building, a single indicator is used in the Swedish EPC – the EP value (unit). This indicator is based on purchased energy and weighting factors used for normalizing the value with respect to weather, climate condition and primary energy. However, no such indicator exists for the evaluation of the indoor environmental quality (IEQ), even though IEQ is equally important. Nowadays, it is well reported that the effort to improve energy efficiency of buildings may negatively influence the IEQ, in case adequate attention is not paid to this problematic [8], [9]. Improving the building's air tightness for example can lead to reduction in ventilation rates, resulting in poor indoor air quality (IAQ). Therefore, it is important to pay attention to buildings' performance in relation to IAQ, along with their EP and explore if an EP value is at all related to indoor air quality.

A previous study conducted on a sample of 27 school buildings in Gothenburg has shown that a certain relationship can be found between EP value and some measured indoor air quality indicators. These relationships were stronger for buildings equipped with CAV or VAV systems, compared to buildings with natural ventilation or with exhaust systems [10]. Another study conducted on the same building sample has revealed that the IAQ is better in buildings equipped with CAV and VAV systems compared to those naturally ventilated or using exhaust ventilation [11]. This highlights the significance of buildings' ventilation type that merits further investigation.

This study partly builds on the results from the previous analyses [10], [11], and, using the national EPC database, attempts to analyse the Swedish school buildings' EP. The aim is to explore how the EP is influenced by the ventilation system type, information which is available in the EPCs. The study also aims to compare the investigated values with results from other European studies focusing on energy use in school buildings.

2. Methodology

2.1. EPC database

The GRIPEN database extract containing the EPC data was provided by the National Board of Housing, Building and Planning (Boverket) in the form of text files. The database was provided in November 2019 and therefore does not contain any records issued after this date. The data was provided in two separate databases, as there was an important change in methodology enforced in 2019. Before this date, the Swedish EPCs used EP value as the main certificate rating. In 2019, the primary energy value was introduced as the main indicator, but the older indicator is still present in the newest EPC version. However, as the majority of the EPCs have been issued before this major change, this study works with the older indicator – the EP value ("energiprestanda" in Swedish) and not with the primary energy value.

2.2. EPC variables used in the study

This study works with several variables included in the dataset. Table 1 provides an overview and detailed description of the variables used in this study.

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Table 1. Description of variables used in the study.

Variable	Units	Description
Floor area	m^2	Heated floor area of the building. This value is used for calculation of energy performance value per m^2.
Year of construction	years	Year of construction of the building as stated in EPC.
Property electricity	kWh/m^2.year	Electricity used for building operation – ventilation systems, pumps in the heating system (not heat pumps), lighting in common areas (halls, technical rooms etc.). Low or no impact of building users on this value. Not-normalized value. In EPC available as a total value for the whole building. For this analysis, total value was divided by heated floor area to get the value per m^2.
Energy performance	kWh/m^2.year	Energy performance value of the buildings. Normalized value based on purchased energy. Consists of energy for space heating, DHW, cooling and property electricity. This value does not include the tenants' electricity use.

Swedish EPC contains only basic information about the buildings ventilation system. The possible ventilation types are the following:

- Supply and exhaust mechanical ventilation with heat recovery system (MVHR) – the air is mechanically supplied and exhausted using ventilation unit. The heat from exhausted air is recovered and used for preheating of the supplied air.
- Mechanical exhaust ventilation (MEV) – the air is supplied through windows, leakages, or vents, and mechanically exhausted.
- Supply and exhaust mechanical ventilation system without heat recovery (MV) – the air is supplied and exhausted using ventilation unit, without heat recovery system.
- Natural ventilation (NV) – works as the MEV, but the air is exhausted via a duct based on the density difference between warm (indoor) air and cold (outdoor) air.
- Mechanical exhaust ventilation system with heat recovery (MEVHR) – works as the MEV, but the exhausted heat is recovered and used for heating or DHW preparation (most common type: exhaust air heat pump - EAHP).

Some buildings are equipped with more than one ventilation system type. Based on the information provided in the EPC, it is not possible to determine which system is predominant in the building.

The Swedish EPC also includes information about the design ventilation air flow and if the obligatory ventilation inspection (OVK) is carried out. This should be stated in the EPC; however, the ventilation control is not always confirmed, and the air flow is not filled in a consistent way and in many cases it is even missing. Where stated, the values range from 0,35 to 10 $l/s.m^2$.

2.3. Sample preparation

The original database contained EPCs for all building types in Sweden. In Swedish EPCs, special categorization introduced by Swedish Tax Agency (Skatteverket) is used to distinguish among different building types. Only buildings belonging to the category ”825 Special unit, school building” were retained. This category comprises buildings for education or research, i.e. primary and secondary schools as well as universities. Kindergartens are not included.

The following bullet points describe the process of dataset cleansing:

- EPC records with exceptionally large floor areas were removed (upper 1%) to avoid distortion of the results by extreme outliers.
- EPC records identified with more building use types, such as swimming pools or canteens, were removed, as these are usually operated in a different way and have different energy demands.
- EPC records with missing or zero value of property electricity were excluded.

- EPC records where the heated floor area was derived from other types of floor areas using a coefficient and not directly measured were excluded to avoid a potential error in final EP value. Using an incorrect heated floor area results in either over- or under-estimation of the EP value. This problem was observed in the oldest versions of EPCs and is well described in literature [12].

No buildings were filtered out based on the value of EP, as Boverket already excluded those exceeding 500 kWh/m^2, assuming that numbers are too high and probably incorrect.

The final sample consists of 8404 EPC records. One record usually represents one building, however in some cases it can also represent several buildings, for example when the buildings share the same HVAC systems. The decision is usually up to the energy expert compiling the EPC. In this analysis, one record is considered as one building for practical reasons.

In Sweden, the final EP value is in most cases based on the measured energy values. Therefore, it reflects the purchased energy and not the calculated building energy demand. Some of the sub-values provided in the EPC, such as property electricity value, are in many cases derived from the final value using qualified estimation of the energy expert.

2.4. Statistical measures and tests
The data was investigated as well as analysed using RStudio software. As the distribution of the data is not normal and outliers appear in all investigated variables, median value is used to describe the centre and interquartile range (IQR) is used as a measure of spread. However, for comparison with other studies, mean values and standard deviations are also calculated in certain cases. Non-parametric Kruskal-Wallis test was used to calculate if there is a statistically significant difference among the explored groups. To find the pairs which are significantly different, Wilcoxon rank sum test was used.

2.5. Literature review
A literature review was conducted to find other studies focusing on energy use in school buildings. The focus was to identify literature working with school building samples in Europe. Only studies with a representative sample, i.e. sample representing the whole country or certain region, were included in the comparison. Studies investigating only a small number of schools were excluded from this review. Studies working only with primary energy values were also excluded. The literature search was not limited to studies using EPC data but was also extended to studies that used measured energy values.

The results of the search revealed that most European studies focusing on school buildings' EP comes from UK and Greece. Other studies originate from several other European countries, such as Sweden, Finland, Cyprus or Luxembourg. Results from these studies are presented and compared to the values investigated in the present paper.

3. Results
This section presents the results of the analysis, focusing on buildings' EP values and ventilation system.

3.1. EP values in relation to basic building characteristics
Basic characteristics of the entire investigated dataset consisting of 8404 EPC records are also shown in Table 2.

Table 2. Basic characteristics of the investigated EPC dataset

Total heated floor area *[m^2]*	Floor area median/mean *[m^2]*	Energy performance median/mean *[kWh/m^2.year]*	Energy performance IQR/standard deviation *[kWh/m^2.year]*	Property electricity median/mean *[kWh/m^2.year]*	Property electricity IQR/standard deviation *[kWh/m^2.year]*	Year of construction median
12 604 365	798/1500	150/155	67/57	20/24	14/15	1970

The derived mean EP value is much lower than the value from another study, which aimed to characterize the Swedish building stock [13], including school buildings, using EPC database extract from 2015. The study found that the median energy performance of all school buildings was 165 kWh/m^2 (mean 172 kWh/m^2). However, it comprised the entire dataset and did not exclude certain records as was done in the present study, i.e. school buildings identified also with other types of buildings, with derived floor area etc. Using questionnaire surveys, the Swedish Energy Agency derived much lower mean value – 129 kWh/m^2 [13].

The analysis of the information regarding obligatory ventilation inspection has shown that at the time of the EPC issuing, 6648 buildings (79%) had this inspection conducted and completed. 1723 (21%) buildings had the inspection either not completed or not conducted at all. In 33 cases, this information is missing.

The analysis of heat supply systems has shown that in 68% of the buildings in the sample, only one heat supply system is indicated to be used in the building. In the remaining 32%, a combination of more systems is used. District heating is the most prevalent heating system type used in Swedish schools. In the sample of 8404 EPC records, district heating is used in 5439 buildings (65%). Oil boilers are used in 672 buildings (8%), wood chips, pellets or briquettes boilers in 533 buildings (6%) and gas boilers in 154 (2%). Use of fossil gas as a fuel is typical only for south-western part of Sweden. Wood logs and other biofuels are used in only 3 and 8 buildings, respectively. In 32% of all the buildings in the dataset, electricity is used for heating. Heat pumps are used in 846 buildings (10%), with ground-source heat pump being the dominating type. 1047 buildings (12%) are equipped with electric heating panels, 1023 (12%) with electric boilers, and 568 (7%) use electric air heating.

3.2. Ventilation systems analysis

Analysis of the investigated sample has shown that supply and exhaust mechanical ventilation system with heat recovery is present in 7509 buildings, which constitutes 89% of the investigated sample. In 72% of the cases, it is the only ventilation system present in the buildings, i.e. no other system type is indicated in the EPC in these cases. Considering supply and exhaust heat system either with or without heat recovery, it is present in 94 % of the buildings in sample. Some form of mechanical ventilation system (MVHR, MV, MEV, MEVHR) is present in 98% of all the buildings in the investigated sample. This is a strong contrast compared to the situation in other European regions, where natural ventilation highly prevails, as described in the SINPHONIE study [14]. The sample in this study was chosen to represent each country's typical building stock. 86% of the 114 buildings across 23 European countries investigated in this study were naturally ventilated, 7% were equipped with mechanical ventilation system and the remaining 7% with exhaust systems. This study also reported that in the Northern Europe cluster (in which Sweden was included) had the highest mean ventilation rates per child (3.39 l/s) compared to the rest of Europe (0.87- 1.82 l/s), although still inadequate based on the National requirement [15]. Another study from England and Wales reported that 97% of the buildings were predominantly naturally ventilated [16].

For the detailed ventilation analysis, only the buildings with one type of ventilation system indicated in the EPC were included. Buildings equipped with more ventilation system types were excluded to avoid mixing the effect of different systems on energy performance. In addition, buildings equipped with MEVHR were also excluded, as there are only 8 buildings having this system. Therefore, this analysis included 6834 buildings (81% of the former sample). Table 3 provides an overview of the detailed ventilation analysis results.

Table 3. Overview of energy performance values, property electricity and year of construction for different ventilation system types

Ventilation system type	Number of buildings	Heated floor area median *[m²]*	Energy performance median *[kWh/m².year]*	Energy performance IQR *[kWh/m².year]*	Property electricity median *[kWh/m².year]*	Property electricity IQR *[kWh/m².year]*	Year of construction median
MVHR	6083	783	147	65	21	13	1973
NV	133	309	157	85	8	16	1940
MEV	279	411	167	80	15	12	1963
MV	339	732	185	72	20	15	1968

The results show that there are differences in the median value of EP between various ventilation system types. As expected, the lowest EP value can be observed in buildings equipped with heat recovery system (MVHR) and higher EP values in buildings with mechanical systems without heat recovery.

The results suggest that the property electricity value is to a high extent influenced by the ventilation system type in the building. The highest median value is in buildings with mechanical extract and supply systems. However, as seen from the EP values, the presence of heat recovery system compensates for the increased electricity use for ventilation systems. Moreover, the presence of mechanical systems with air filtration contributes to better IAQ, as documented in the previous study [11].

Statistical tests have shown that the differences in EP value and property electricity value between ventilation system types are significant ($p < 0.05$). In the case of EP, there is a statistically significant difference ($p < 0.05$) between all pairs apart from MEV-NV. In the case of property electricity value, the difference is statistically significant ($p < 0.05$) between all pairs apart from MVHR-MV.

The highest IQR of EP indicates the variation in EP between naturally ventilated buildings. This is in line with the results presented in the previous study [10], where buildings predominantly naturally ventilated or using only exhaust systems showed the highest variability in both EP and certain indoor air quality indicators. Such variation is most likely a sign of the influence of buildings' occupants, which is much stronger compared to mechanically ventilated buildings. However, no conclusion can be made without additional information about the buildings.

4. Comparison with other European countries

According to the Swedish Energy Agency statistics from year 2020 [17], the main fuels used for the district heating generation in Sweden are wood fuels and renewables (biogas, biooil) (36,7%), municipal solid waste (31,7%), followed by heat from heat pumps (8,4%) and waste heat from industry (8,2%). Less than 3% of the energy originates from fossil fuels. In case of electricity generation in Sweden, 17% came from wind power, 46% from hydropower, 29% from nuclear power and only 8% from conventional thermal power. This is a strong contrast to some other European countries, such as Germany, where 50% came from the conventional power [17].

The electricity use per capita in Sweden is higher compared to other countries. In 2020, the electricity use per capita was 12,3 MWh, compared to 6,4 MWh in Germany, 4,8 MWh in Greece or 4,5 MWh in the UK [18]. This is also reflected in the ratio of the buildings using electricity for heating in the dataset, which is quite high (32% of all buildings in the full dataset of 8404 EPCs).

A study conducted in England [19] using Display Energy Certificates of approximately 8500 school buildings reported the median value of total energy for primary schools, secondary schools and academies 180, 183 and 193 kWh/m^2 with IQR 67, 66 and 74 kWh/m^2, respectively. The Display Energy Certificates state the measured energy values. This study has also found that schools with mechanical ventilation have statistically higher use of electricity compared to those being naturally ventilated, with the averages of 49 a 44 kWh/m^2, respectively. However, mechanically ventilated schools have on average lower fossil-thermal energy use by 21 kWh/m^2. In another study conducted in UK [20] with 10 734 primary and 1 425 secondary schools in the sample, a difference in electric intensity use (2-9 kWh/m^2 depending on the type of the school – primary/secondary) was observed between schools ventilated naturally and mechanically. These differences are lower than those observed in the present study, i.e. 13 kWh/m^2 between MVHR and NV.

An analysis of a total of 342 Hellenic primary and secondary school buildings [21], not equipped with any mechanical ventilation systems, revealed that the median electricity use is 28,2 kWh/m^2. However, this value includes also lighting in classrooms and other areas (that is not included in the Swedish property electricity value where only facility electricity is included). The lighting is the major contributor to electricity use with 19,6 kWh/m^2 (median value). The Hellenic study also states that lighting is the second major contributor to final energy use intensity, following space heating being the first one. The median floor area of the school buildings was 1375 m^2 with calculated median energy use intensity 79,1 kWh/m^2. The median value for the warmest climate zone was 68,4 and for the coldest climate zone 187,7 kWh/m^2. The most common heating system includes fuel fired boiler. Oil-fired boilers are the prevalent system (71%), being followed by gas-boilers (28,3%). Heat pumps as the main heating system are used only in 1% of the schools, and in 7% of the cases as a supplementary heating system. This context is clearly in great contrast to the Swedish context analysed in the present study. The median value of heating demand for school building was 29,3 kWh/m^2, with IQR of 33,3 kWh/m^2.

A study focusing on schools in Cyprus [22] revealed that their energy use consists mainly of electricity and heating oil. All schools are equipped with central oil heating system. The annual average delivered energy was 62,75 kWh/m^2 (24,17 kWh/m^2 of electricity and 38,59 kWh/m^2 for heating).

In Finland [23], the median total energy performance of 134 schools in Helsinki and Tampere region, representing 48% of all schools in the area, was 202 kWh/m^2. The median value of space heating was 155 kWh/m^2 and of electricity 48 kWh/m^2. All the values represent measured energy use.

An analysis of 68 school buildings from Luxembourg [24] showed that those using district heating or pellet boilers use less thermal energy than buildings using oil as a fuel. However, when looking at the year of construction, it was concluded that the age of the building is the main determinant for the energy use as the buildings equipped with pellets boilers were mostly the newest buildings and buildings with oil boilers, which were among the least energy efficient, belonged to the oldest group. These findings are in line with the results of this study. An average thermal energy use was 93 kWh/m^2 and average electricity use 32 kWh/m^2. The values were adjusted to the average climate using normalization process.

Comparison with studies from other countries appeared to be rather complicated, as the approach to the topic is different between studies, and different methodologies, such as normalization techniques, are followed when analysing the energy values. Similar conclusion was made in a review paper focusing on possibility of comparing the energy performance in schools [25]. In addition, it is not rare that essential contextual information about the buildings is missing, such as description of the ventilation type in the building. As seen from the results in the present study, the ventilation system influences the energy use in the building in many ways – both the electricity use and the final EP, therefore it is important that this information is included. Also, many studies lack the breakdown of what is included in certain values, such as in the reported electricity values. This makes comparison almost impossible, as only trends and tendencies can usually be compared.

Other studies confirm that there are differences in energy use when part of the building has a different usage, such as school canteen with kitchens, swimming pool or gym. The influence on EP can be up to twenty percent [24]. Therefore, EPCs identified with other uses of the building were excluded in the present study. This is another factor that need to be considered and clearly stated in the analysis so that the results are not distorted when analysing the EP.

5. Limitations of Swedish EPCs

The Swedish EPCs lack more information about the building construction, such as information about the envelope, making it impossible to use it for comparing the envelope quality with other studies, but also to help answer certain questions raised when analysing the results. Building's envelope characteristic is a standard part of EPC in most other countries, as it is a necessary input for the calculation of EP. However, when conducting Swedish EPC, this information is usually not needed, as the EP value is based on purchased energy. Still, adding this information to EPC would be a great benefit for various analysis using EPCs as well as for planning the renovation strategies.

The literature suggests that there might be certain differences between different types of schools (e.g. primary vs secondary schools) due to differences in operation, which could have an effect on the EP value [19]. However, another study claimed that the different type of usage did not influence the average values of energy use [24]. It would be beneficial to analyse different types of schools separately to identify if the differences exist. Unfortunately, it is not possible to distinguish between different types of school buildings, such as primary and secondary schools, in the investigated dataset, as this information is not included in the Swedish EPC.

To provide a better indication of the building's IAQ, more detailed information about the ventilation system types in the building should be included in the Swedish EPC. Nowadays, only indication of the present system types in the building is given, however it is not possible to decide which is the main system. Indicating the percentage of floor area served by each respective system could be a simple improvement providing both better information about IAQ to building users and increasing the opportunities for better understanding of the building stock.

6. Conclusion

The focus of this study was to use the EPC database to analyse Swedish school building stock, with a special attention paid on the ventilation system types.

The Swedish EPC is developed to establish the energy used to calculate the energy performance. It is not developed to make detailed analyses of ventilation systems used in the buildings. It is also difficult to compare the results with studies based on EPC in other countries. It can thus be concluded that the EPC need to be re-developed with more specific information to enable more detailed evaluations with an increased value for the building owner, as well as the EU-community.

It can however be concluded that Swedish schools are mainly heated using district heat followed by electricity using electric boilers, electric heat pumps (mainly ground source) and electric panels.

This means that there are relatively few schools heated with fossil fuel (oil, natural gas) boilers. It can also be concluded that Swedish schools are mainly ventilated using (mechanical) exhaust and supply air systems with heat recovery. This means that there are relatively few schools with simpler (mechanical) exhaust air or natural ventilation systems. There is also a clear relation between the type of ventilation systems and the property electricity.

Swedish district heat is dominated by solid biofuels and waste heat and the Swedish electricity generation is dominated by hydro, nuclear and wind power. This means that the energy supply of Swedish schools (and Swedish buildings in general) has a relatively small contribution to the global warming in comparison to European buildings in general. There is however a wide variation in energy performance, showing a potential for improvements.

The current version of EPC does not provide any information about the indoor environment, but Swedish schools can likely provide improved air quality in comparison to schools in other EU-countries. Mechanical exhaust and supply air ventilation systems with heat recovery offer in general better conditions to provide good air quality, at the same time as they reduce the heat demand, in comparison to simpler systems as mechanical exhaust air and natural ventilation systems.

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