Licentiate Thesis in Civil and Architectural Engineering

Energy Performance Certificates

Labelling in society and new buildings

CAMILLA HJORTLING

KTH ROYAL INSTITUTE OF TECHNOLOGY

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Abstract

Energy Labeling Buildings – A comment

This thesis investigates energy regulation in Sweden and its consequences for energy efficiency in buildings.

The first study and article contribute to defining the current energy consumption baseline for buildings in Sweden. The data used for the analysis are extracted from the database of the Swedish National Board of Housing, Building and Planning and consists of 186,021 measured energy performance certificates issued for commercial buildings (355 Mm^2), collected during 2007–2015.

The results from that study for certain building types, construction periods, climate zones and energy use are presented. Building codes have influence on the building's energy performance. When new building codes have been adopted and energy performance requirement have been stricter the measured energy consumption has been lowered compared to buildings built earlier. New buildings have nevertheless often higher energy consumption than stipulated by the building code.

The first Swedish Energy Performance Certificates (EPC) that were studied were quite reliable because they were based on energy bills and not on theoretical calculations. This has now changed and are now aligned with EU regulation.

The second article and study focuses on the Swedish building code regarding the energy consumption of buildings, and the calculation of which should be included in a building permit. The energy performance certificate (EPC) of a building documents the actual energy performance, which provides an opportunity to compare the actual energy consumption with what was planned and what was built. Here, this comparison is done for buildings in the city of Stockholm raised in the period from 2010 to 2015.

The first observation in this second study was that in official listings as the taxation register, the EPC database and the building permits, data files are missing. It would be useful to coordinate and develop the collaboration between different authorities and develop a national database with this information.

However, for the buildings with summited documents the mean energy consumption according to the EPCs is close to what has been requested in the building code. So, in general, the building code is fulfilled.

When the energy consumption according to the EPC is lower than planned, the explanation relates to changes or miscalculation in Atemp, erroneous ventilation flow in calculations or that the EPCs are only based on calculations.

For commercial buildings, such as restaurants, server halls, and sport facilities with various internal loads, there should be a focus on the total energy demand in building as one unit with the operations in the unit. The EPC should offer an opportunity for follow-up on the planned energy performance.

Sammanfattning

Energimärkning av byggnader - En kommentar

Denna avhandling undersöker regler för energianvändning i byggnader i Sverige och deras konsekvenser för energieffektivitet i byggnader.

Den första studien och artikeln bidrar till att definiera den nuvarande baslinjen för energiförbrukning för byggnader i Sverige. Data som används för analysen är hämtade från Boverkets databas och består av 186 021 uppmätta energicertifikat utfärdade för kommersiella byggnader (355 Mm^2), insamlade under 2007–2015.

Resultaten från den studien för vissa byggnadstyper, byggperioder, klimatzoner och energianvändning presenteras. Byggnadsnormer påverkar byggnadens energiprestanda. När nya byggregler har antagits och kraven på energiprestanda blivit strängare har den uppmätta energiförbrukningen sänkts jämfört med tidigare byggda byggnader. Nya byggnader har dock ofta högre energiförbrukning än vad byggreglerna föreskriver.

De första svenska energideklarationerna som studerades var ganska tillförlitliga eftersom de baserades på energiräkningar och inte på teoretiska beräkningar. Det har nu ändrats och är nu anpassat till EU:s lagstiftning där beräknade värden används.

Den andra artikeln och studien fokuserar på den svenska byggnormen avseende byggnaders energiförbrukning och energiberäkningen som ingår som underlag till bygglovet. Energideklarationen upprättas två år efter att byggnaden är uppförd och dokumenterar den faktiska energiprestandan, vilket ger möjlighet att jämföra den faktiska energiförbrukningen med det som planerats och det som byggts. Här jämfördes underlag för byggnader i Stockholms stad uppförda under perioden 2010 till 2015.

Den första observationen var att officiella listor från Skatteverket, energideklarationsdatabasen och bygglovsdatafilerna inte stämde överens - det saknades underlag. Det vore bra att samordna och utveckla samarbetet mellan olika myndigheter och utveckla en nationell databas.

Men för byggnader med sammanställda dokument ligger den genomsnittliga energiförbrukningen enligt energideklarationen nära vad som efterfrågats i byggnormen och som redovisats i beräkningar vid bygglovsansökan. Så i allmänhet är byggreglerna uppfyllda.

När energiförbrukningen enligt Energideklarationen (EPC) är lägre än planerat, förklaras detta av förändringar eller felberäkningar i Atemp, felaktigt ventilationsflöde i beräkningar eller att EPC:erna enbart baseras på beräkningar.

För kommersiella byggnader, såsom restauranger, serverhallar och idrottsanläggningar med olika interna laster, bör det vara fokus på det totala energibehovet i byggnaden som en enhet med verksamheten i enheten. EPC bör erbjuda en möjlighet till uppföljning av den planerade energiprestanda.

Preface and acknowledgements

The research work presented in this licentiate thesis was conducted during 2015-2026 at the Division of Sustainable Buildings, Department of Civil and Architectural Engineering at KTH Royal Institute of Technology in Stockholm, Sweden. Professor Folke Björk, PhD Tord af Klintberg and Adjunct Professor Magnus Berg have been the supervisors. KK-stiftelsen and Vattenfall AB funding for this PhD position is gratefully acknowledged. The author would like to express our gratitude to the National Board of Housing, Building and Planning for providing us with an extract of the GRIPEN database.

To my supervisors, without your support and guidance, this licentiate thesis would not have been possible. Thank You Folke Björk for your patience. Thanks to all the colleagues at the Department of Civil and Architectural Engineering for creating an inspiring working environment, Kjartan Gudmundsson, Sasan Sadrizadeh, and Parastoo Sadeghian for sharing your knowledge. And the support from colleagues and managers at Vattenfall, Fortifikationsverket and Trafikverket is appreciated. The work at field in different communities and the support as such with special recognition to Stadsbyggnadskontoret Anci Gidnäs-Pettersson and especially Boel Afzelius Ekerö Community for fruitful discussions and on-site deduction in commercial buildings. Many thanks are extended to my colleagues and friends for the rewarding discussions and support.

Finally, thanks to family and friends for your support. Special thanks to my dear friend Tord af Klintberg and also Ivo Martinac for thinking of me when KK-stiftelsen searched for resources, which made these PhD studies possible. To my beloved Rickard Hjortling, I am endlessly grateful for your support and foremost, your database assistance.

Stockholm, January 2026

Camilla Hjortling

List of Publications

Paper I

Hjortling C, Björk F, Berg M and Klintberg T (2017) "Energy mapping of existing building stock in Sweden - Analysis of data from Energy Performance Certificates," Published: Energy and Buildings, vol. 153, pp. 341-355, 2017.

Paper II

Hjortling C, Björk F, Berg M and Klintberg T (2026), Planned versus outcome - Energy in buildnings, To be- Submitted

The planning, data collection, writing and analyses were primaly performed by the main autour. The co-authors have contributed with discussions about the results.

CONTENTS

1 Introduction

In the beginning of this work, the author asked -Why would the author or anybody else want to know more about energy in commercial buildings?

1. Regulation [1], [2], [3] for buildings
2. Data available for analyses [5],[53], [54]
3. For the author personally it was also the opportunity to explore a new field for business as it is for many others as well and also the demand leading to regulation and labelling. The author have have a enourmus use of Figure 1 and especially Figure 2.

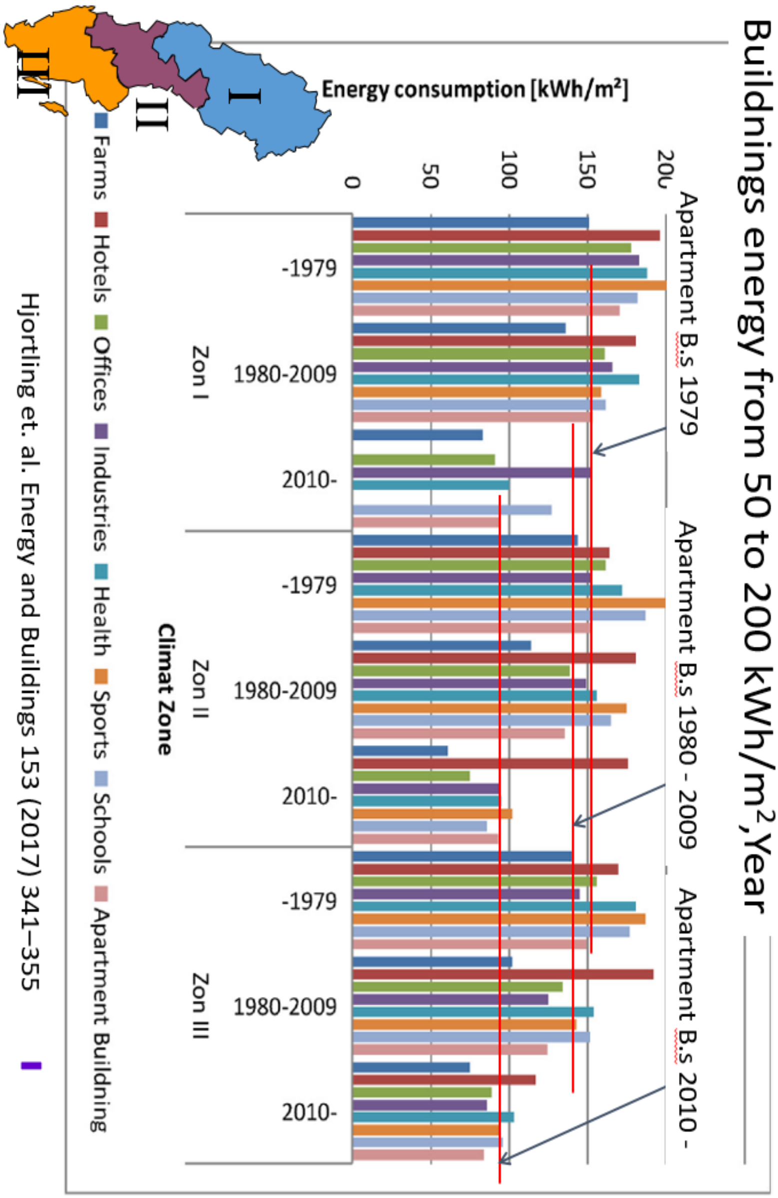

Figure 1) Energy Consumption in Sweden, Paper I

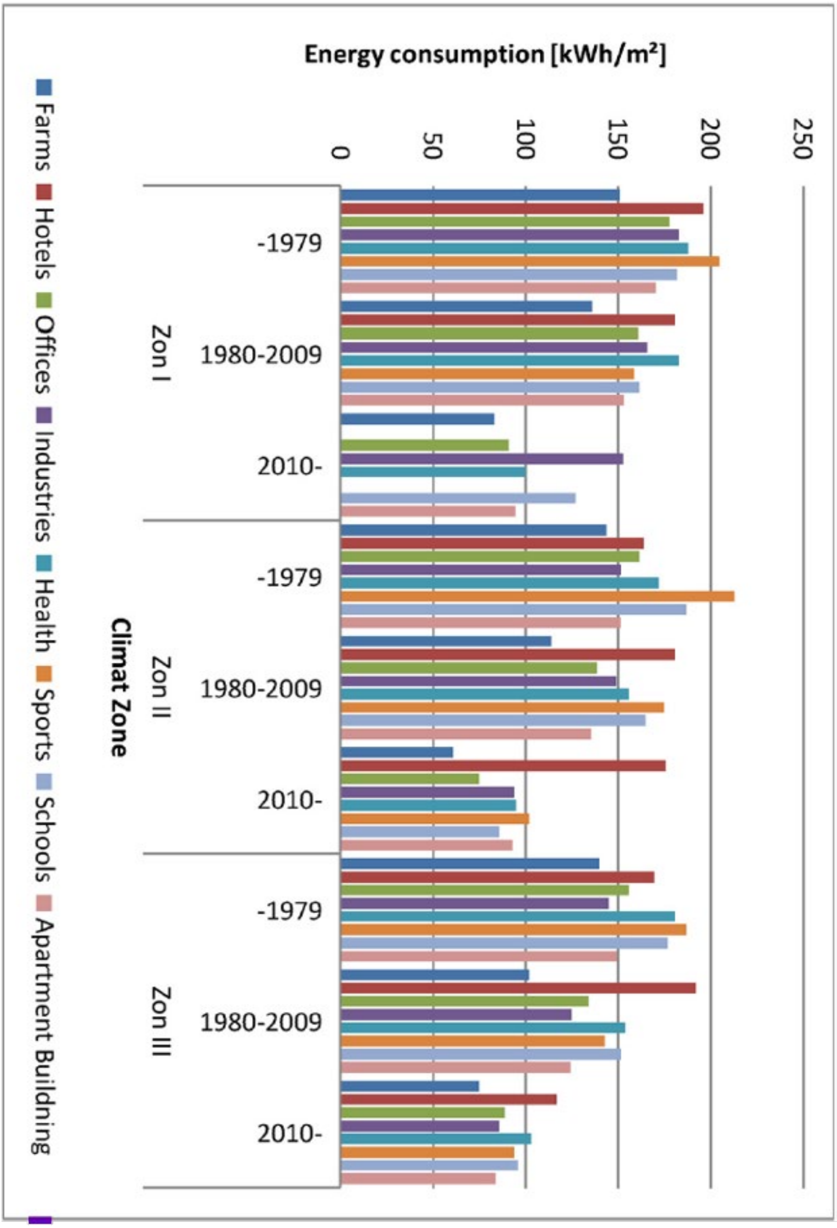

Figure 2) Energy Consumption in Sweden, Paper I

And also due to the new situation in the Swedish energy system and the new global security trends in this part of the world where energy supply is a soft target makes this field of interest even more current.

-What is the big question? - Do the aims for original EU-legislation get fulfilled by the EPCs being done now in Sweden?

- Do EPCs mitigate the climate? – No, not at the current state focusing on calculated performance.

1.1 People before us in history – what can we learn?

Building regulation have been in place already in the ancient Babylon civilization as the Code of Hammurabi 1754 BC [41] written on 2.4-meter-high black stone.

There have also been laws and labelling systems for product and services as in England during the 13th- century a law called the Assize of Bread and Ale [7] and in China during 9th century the Tang Code that includes regulation of grain, food, luxury goods and properties [8].

The industrial revolution during the 19th century formed the London Building Act of 1844 [9]. In Sweden we have had building regulations regulation for thermal insulations since 1947 [10]. The Energy conservation in the Building act of 1976 in the United States was a response to the energy crises of the 1970s which highlighted the need for energy efficiency [11] In our 21th century we have focused on safety, accessibility, energy efficiency and environmental sustainability [12].

In 2010 EU focused on Nearly-zero energy buildings. It means that all new buildings from 2020 shall have a high energy performance and very low-energy needs, covered largely by onsite and nearby renewable energy sources [13].

According to a 2021 report, the European Commission's Joint Research Centre found that the energy performance regulations consequence during the period 2005-2018 decreased. In the residential sector, improvements in energy efficiency as well as warmer winters have led to a 10% reduction in the final energy consumption while in the services sector, the final energy consumption increased by 2% mainly due to economic growth. However, the renovation rate is still very low. The Commission also launched a new buildings database – the EU Building Stock Observatory, to track the energy performance of buildings across Europe [14].

And beyond the 21th century- form the history and also the technical development of AI - we can expect that the big trend is that the laws and labelling will be more complicated and specific and also more rapidly changed- they will also be publicly displayed however in a smaller format.

1.2 The purpose of this work

The aim of this work is to fill a knowledge gap regarding the availability and use of configuration information in the context of buildings constructed. And the vast amount of data in the database where the energy certificates have been gathered offers an opportunity to analyse data about energy consumption in the Swedish building stock. The main data source is the Swedish data base of energy certificates [5].

This thesis is based on two studies;

The first study and article contribute to defining the current energy consumption baseline for buildings in Sweden. The data used for the analysis are extracted from the database of the Swedish National Board of Housing, Building and Planning and consist of 186,021 measured energy performance certificates issued for commercial buildings (355 Mm^2), collected during 2007–2015. This is referred to as Paper I.

The second study focuses on the Swedish building code regarding the energy consumption of buildings, and the calculation of which should be included in a building permit. The energy performance certificate (EPC) of a building documents the actual energy performance, which provides an opportunity to compare the actual energy consumption with what was planned and what was built. Here, this comparison is done for buildings in the city of Stockholm raised in the period from 2010 to 2015. This is referred to as Paper II.

In these studies, the central part is data extracted from the energy performance certificates collected into a Swedish national database were used in this research. The different kinds of building types are described in detail later. Due to confidentiality issues, all data that could identify the building, the building unit, or the building owner were removed from the data set. For each energy performance certificate, the following variables were extracted:

energy consumption (kWh), energy performance (kWh/m^2) and building type (multi-dwelling buildings, farms, schools, health care facilities, factories, restaurants and hotels, and other rental facilities such as offices), year of construction, climate zone, its heated floor area (as described in Section 4.1) and the shares of the energy devoted to heating, cooling, hot water, and electricity for the facility.

In Paper II calculated energy performance for the building permit and submitted EPC´s for the finale building are compared.

1.3 Limitations

The purpose with Paper I, main study, are limited to energy use in Swedish commercial buildings. Detailed analyses of the regulatory framework such as the Swedish National Board of Housing, Building and Planning´s (Boverket) building classification system (A-F), is beyond the scope of this research.

The timespan of the dataset, while subnational, may not fully capture long-term trends in building energy performance. This is because construction lifecycle from planning to completion often exceeds several years. Consequentially signific changes in construction methods or materials are not included in this studies.

2 Background

Access to energy and how it is used is interesting. In this study the author had the opportunity to study one of the largest and first databases in Sweden that collected EPCs issued, Paper I. And also building permits, links to tax databases and outcomes, albeit on a smaller scale, which provided the data basis for Paper II for Sweden's capital Stockholm.

The author had some questions and got some answers and even more questions. The author invested both time and financial means- therefore it is crucial study the results as we can learn from them and improve.

3 Research questions

The research questions in Papers I and II are summarised in this chapter.

3.1 Research questions in Paper I

In this section the questions asked in Paper I are summarised. In Paper I data from the Swedish database of EPCs were used to evaluate the energy performance of the Swedish building stock [5]. The database containing all Sweden's energy performance certifications EPCs at the moment the data were retrieved are the current valid EPC´s that can be evaluated to yield answers to a number of research questions:

1. How is energy consumption influenced by the climate zone? Are the buildings well-adapted to the climate?
2. How is energy consumption related to the building category?
3. How is the breakdown of energy consumption distributed according to typology and end use?
4. What effect did changes in the building code have on buildings' energy performance?
5. How is energy consumption influenced by year of construction?
6. What is important to consider when planning new commercial buildings in Sweden?
7. What does EPCs tell us about the building code regulation after 2006 with rapidly stricter regulations and the actual outcome of this stricter regulation?
8. How can EPC´s be improved?

3.2 Research questions in Paper II

A comparison between the values given in the energy performance certifications and the energy performance calculations for the building permission can be evaluated to give answers to a number of research questions:

1. How big is the energy consumption presented in the EPC compared to the energy performance calculated in the planning phase? What do energy calculations tell us about the building code regulation after 2006 with rapid changes towards stricter regulations?
2. Why does the energy consumption differ between the calculated and the EPC values? Do we have obvious reasons for these deviations?
    i. Do the calculation programs have relevant data input to do a successful calculation and if so, do the construction documents provide sufficient information for implementation of the energy solution at site? What parameters or variables make the calculation different from the outcome?
    ii. Are there other faults to blame such as training of energy experts, changes of the codes too often, lack of clear responsibilities, lack of testing and training, building processes?
    iii. Are there any differences between owner groups or calculation companies?

3. How can the building performance be improved? What is important to consider when planning new buildings in Sweden?

The results will be valuable to regulators, developers, energy planners, designers, building owners, and building officials.

By providing new information on the correlation between calculated planned energy performances in the documentation for the building permits compared to energy performance certificates in Sweden, this study enables new opportunities to be developed. In the comparison between EPC and project phase calculations, a number of building characteristics are compared.

4 Method and sources

In Paper I data from the Swedish database of EPCs were used to evaluate the energy performance of the Swedish building stock [5]. It was noted how energy consumption per square meter decreased over time, probably due to the introduction of more stringent rules in the building code. The aim of the work in Paper II was to evaluate the extent to which new buildings in Sweden fulfil the requirements for energy performance stated in the building code, and are therefore also presented as attached to the application for the building permit. This is done by comparing data from different sources for a number of buildings in the city of Stockholm that were built between January 1, 2010 and September 13, 2015.

In Paper II a number of data sources are used, that are described below. They are energy performance certificates Paper I, [5] and energy performance calculated in the planning phase which are filed in the archive of the city planning office in the city of Stockholm [54]. These data are also related to the data about energy consumption in the Swedish building stock that are collected by the Swedish Energy Agency. The number of buildings in the data set is compared with information from the Swedish taxation authority [53].

4.1 Energy performance certificates in Sweden

The energy consumption data in the EPC´s in Sweden are based on energy bills for heating the building and energy for warm tap water, ventilation, and for the facility, like for circulation pumps or elevators or lighting in staircases. Energy consumption is normalized with the area being heated (Atemp) and also to a normalised climate. The Atemp is the floor area for all heated spaces limited by the inner sides of the outer walls and including the cross-section of partition walls, etc. Household energy or energy for activities in the building is not included in energy performance but is sometimes added as additional information in the EPC.

The result is called specific energy and the unit of measure is kWh/m^2 per year.

The EPCs are very often based on the measured energy consumption of the building.

However, it is also allowed to produce the EPC using a calculation of the energy consumption, as mentioned above.

The information regarding the EPCs in buildings in Sweden is uploaded in electronic forms, and these data are stored in the National Board of Housing´s database, which is called Gripen [5].

On May 2, 2011, a new Planning and Building Act (PBL) was introduced, where one of the news was that you must not move into a newly built house until you have obtained a final certificate for the building. Previously, this was not regulated.

The study in Paper II relates to the 227 energy performance certificates issued for buildings (1.9 Mm^2) which are situated in Stockholm, Sweden. These were built between January 2010 and September 2015. The EPCs were done according to the Act (2006: 985) “Energy certification of buildings”. For each energy performance certificate, the following variables were extracted: energy consumption (kWh), energy performance (kWh/m^2) and building type (multi-dwelling buildings, other rental facilities such as offices and other buildings), year of construction, its heated floor area (as described in Section 4.1) and the shares of the energy devoted to heating, cooling, hot water, and electricity for the facility.

In Paper I the author used The National Board of Housing, Building and Planning database, called Gripen, which is a Microsoft SQL-Server 2008R2. The National Board of Housing, Building and Planning staff exported the database into a CSV formatted text file. The author was provided with a link to the file via email so the author could download it and import it into a MySQL database.

For analysis purposes, the data were filtered and extracted from the MySQL database into Excel files and CSV files. In some cases, calculations were performed directly in the MySQL database other calculations were done in Excel or in R. The exceptions are buildings with energy consumption over 500 kWh/m² as the National Board of Housing, Building and Planning excluded those values from the file they provided for the study, having assumed them to be erroneous because they were too high.

4.2 Energy calculations done in the planning phase

The study presented as Paper II is based on the requirement to present energy calculations as a part of the application for a building permit in the city of Stockholm. These documents are filed at the local city planning office of Stockholm [54]. These calculated values constitute the data used in the study.

To be able to read the energy calculation that is handed into the city planning office in Stockholm takes the effort to visit in person and use the computers at site [6]. The information can be extracted in PDF-format and data can be stored in a flash memory for further evaluation.

The data about the calculations in the planning phase in some cases also contain information about:

1. Building code version relevant for this building. Date when the energy calculation was performed
2. Date when the energy calculation was submitted
3. Occupancy type of the building, or type code for taxation
4. Atemp - Heated area
5. Whether the building is qualified for any governmental or local incentive or programs that might give financial support [19]
6. Trade name of energy calculation program used
7. Distribution of energy used for heating, cooling, hot tap water, facility electricity and household and activity electricity

The predicted energy performance in the building permit for a project has the same definition and unit as the energy performance in the EPC. It is the amount of energy to be delivered to the building (usually referred to as purchased energy) in a normal year.

This is energy used for heating, air conditioning, hot water, and appliances such as fans for ventilation, circulation pumps, operation of elevators, or lighting in staircases [3]. Household energy or energy for activities in the building is not always included in the energy performance but are mostly added in the energy calculation programs at some of the early calculations. Examples of household energy are the electricity used for dishwasher, washing machine, drying apparatus (also in common laundry room), stove, fridge, freezer, and other household appliances as well as lighting, computers, TV and other home electronics. The energy performance for heating has been produced by deducting the total energy performance by normal household energy and so on. The building's energy consumption for one year is then divided by the number of square meters of heated area (Atemp). This is the floor area for all heated spaces limited by the inner sides of the outer walls and including the cross-section of partition walls, etc. The result is called specific energy and the unit of measure is kWh/m^2 per year.

The documents filed by the city planning office are usually not organised in a systematic manner. During the process for the building permit sometimes a number of preliminary versions of the calculation are presented besides the final one. This makes it difficult to find the relevant data and to evaluate the process.

4.3 The Swedish Energy Agency's survey for energy consumption in multi-dwelling buildings

The Swedish Energy Agency's energy authority survey for multi-dwelling buildings is conducted annually and it is mandatory to respond to. The survey is sent to owners and managers of the approximately 7 000 buildings. When the outcome of this survey is presented it is not told how many buildings that are included in the results for each category.

4.4 The Swedish tax authority's data base of buildings

The taxation authority has a database of the complete building stock. This is of course established for taxation reasons and is used in Paper II.

The practice of registration of construction year for taxation purposes was established long before any energy labelling was introduced. The Swedish taxation agency classifies real estates by its type code. This data base offers reliable information about the number of buildings for each year of the period studied.

4.5 Short discussion about choice of method

A more comprehensive analysis, potentially yielding more precise conclusions, would have been possible with direct access to high-resolutions data from all grid and district heating companies, combined with the property register, in Sweden. However, such data is protected due to commercial sensitively and legal restrictions (trade secrets, GDPR and so on). Therefore, these studies utilizes the public aggregated data available at the time and it was a standardized dataset at the property level.

5 Answers to research questions

Introduction on research questions answers use the picture.

5.1 Answers to research question in Paper I

This section presents answers to the research questions in Paper I. The first research questions were aimed to investigate how EPC performed in Sweden. The answer, is shown in Figure one previously displayed at page 4 and refers to that this figure is a result in the findings of Paper I:

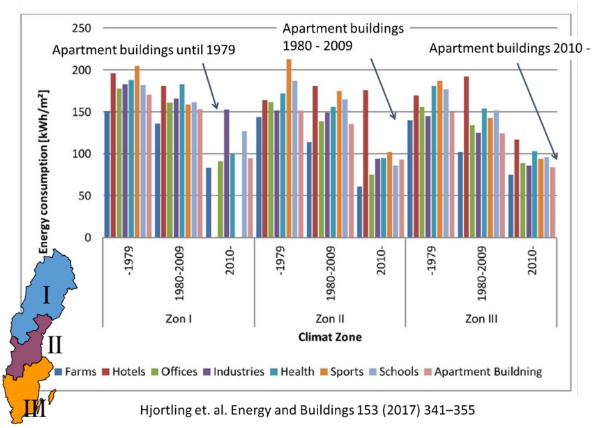

Figure 1) Energy consumption kwh/m² [Reference Paper I]

5.1.1 How is energy consumption influenced by the climate zones? Are the buildings well-adapted to the climate?

The subdivision of the Swedish climate zones I, II and III as indicated in Figure 1 has less impact on energy consumption than the type of building. However, building units in the warmer climate zones have slightly lower energy consumption than those in colder climates, which can be deduced from the results. The only exception is for healthcare facilities in climate zones I and III, which have almost the same energy consumption in all climate zones.

5.1.2 How is energy consumption related to building category?

Looking at the building category in, and then especially at multi-dwelling buildings (which are in the majority with 127,725 certificates and a total of 217.8 M m^2) these labelled buildings have an average energy consumption of 145 kWh/ m^2. The building types with less energy consumed on average are factories and rental premises, mainly offices. The highest energy consumption on average is for hotels and restaurants and for sports facilities.

5.1.3 How is the breakdown of energy consumption according to building type and end use distributed?

Energy consumption according to building type and end use are presented in Paper I. In apartment buildings, space heating stands for 70%, hot water 21% and electricity for facility system support is 9% of the total energy consumption.

No energy is generally needed for cooling in multi-dwelling buildings. The only category that seems to have a need for air conditioning is office buildings. Cooling is represented with 10% (slightly more of this is district cooling, 6%).

Offices also represent the largest part of electricity needed for facility system support with 27%.

5.1.4 What effect did changes in the building code have on buildings' energy performance?

It is noted that building codes have influence on buildings' energy performance.

A consequence of this observation is; when fine tuning regulations, more emphasis should be put into dividing the energy requirements of different building types and stricter regulations require more careful following up on building regulation compliance.

5.1.5 How is energy consumption influenced by construction year?

Modern buildings consume in general, but not always, less energy than their older counterparts. The Swedish building codes for energy consumption have continuously changed over time. And are still changing. [10]. Buildings constructed since 2010 have significantly lower energy consumption for all building categories; for example, multi-dwelling buildings have an average of 85 kWh/ m^2 and hotels and restaurants have the highest energy consumption for recently constructed building units, 122 kWh/m^2. The year of construction is the factor having most impact on energy consumption. The best example of this is modern schools, which consume on average 58 kWh/ m^2 less energy than schools built between 1980 and 2009.

It is important to highlight that building category is a key factor in the implementation of energy conservation measures. It is also important when prioritizing building type to consider the forecast volume of building construction . From the National Board of Housing, Building and Planning report [11], 710,000 households were estimated to be built between 2015 and 2025, 70% of which will be situated in Malmö, Göteborg, and Stockholm (climate zone III).

A closer look at the facts in the National Board of Housing, Building and Planning report [19] (2015:18, page 81) indicates that the increase in population of elderly people over 80 years represents 200,000 households. This will put great pressure on healthcare facilities. Healthcare facilities in climate zone III, where the greatest increases are expected, have in average energy consumption of 103 kWh/ m² and should therefore be in focus. Different types of commercial buildings in Sweden have been analysed, totalling 186,021 energy performance certificates for 355 Mm².

To be able to give recommendations for existing buildings, the energy data should be combined with the information that 60% of all commercial buildings were situated in zone III. This gives the result that the energy regulation for older buildings in zone III should be prioritized.

Since 60% of the available energy certificates apply to buildings situated in the climate zone III and 70% of the new building volume is to be built in climate zone III, the main focus should for this reason be on climate zone III.

5.1.6 What do EPCs tell us about the building code regulations after 2006 with their stricter regulations, and what has been the actual outcome of this stricter regulation?

The Swedish National Audit Office [20] concluded that regular follow-up is missing regarding the EPC outcome. When looking at the building code regulations [3], it is also seen in this study that compliance with regulations is low, as 11% of the recently built multi-dwelling buildings, heated with district heating, consume more energy than the regulation allow. For buildings heated with electricity, this study found that 55% had higher energy consumption than the regulations allow. Therefore, a warning is needed on the EPC label, and follow-up efforts are needed from the regulator. Either regulations on following up the current rules should be adopted or the regulation should be changed. Should there also be an evaluation performed regarding what is possible from a Life Cycle Assessment (LCA) perspective, and question posed about what is theoretically possible and practically possible to achieve?

However, the report from Boverket "Limit values for climate impact from Buildings and an expanded climate declaration" (2023) – states that The European Commission's proposal includes a requirement to calculate the climate impact of new buildings over their life cycle and disclose this in the energy declarations for all new buildings over 2000 square metres as of 1 January 2027 [14]. So, the regulation is still changing.

5.1.7 How can EPCs be improved?

The Swedish database provides many detailed labels of energy are consumption. However, compared to the Spanish analysis [43] some data is lacking. The Spanish label is also based on the carbon dioxide (CO_2) emissions per square meter generated by the building or the building unit in one year, and that is also of interest to the society and users in Sweden. In the Spanish label, carbon dioxide levels are expressed as a letter ranging from A (most efficient) to G (least efficient). Previously, carbon dioxide was included in the Swedish EPCs connected to the energy efficiency actions; however, that part was removed Jan 6, 2023. This paper cannot verify that energy consumption has decreased caused to the legislation.

One remark is that the Swedish EPCs studied in this article are based on data from energy bills. This is a good idea because they talk much about the real case. When using energy database on modelling it should be remembered that all deviations from the ideal case in the model will probably result in higher values. So, using calculated data from an energy software this will probably underestimate energy consumption.

5.2 Answers to research questions in Paper II

This section presents answers to research questions in Paper II.

5.2.1 How high is the energy consumption presented in the EPC compared to the energy performance in the project phase?

5.2.2 What does energy calculations tell us about the building code regulation after 2006 with recurrently stricter demands and the actual outcome of this stricter regulation?

There are differences between calculated and measured values. The main reasons for calculation divergences are:

- Area, only 16 of the 93 assets have the same area stipulated both in the EPC and the project file
- Version of the building code (BBR), only 21 of the 93 assets have stipulated which version of the BBR that is taken in account
- Air flow rates
- EPC is calculated or measured. Calculated values of the EPC tend to differ less from the planned values than measured ones. Here 15 or 16 of the assets had values that were calculated.
- The part being heat in the energy performance value is the main reason for differences between the calculated value and the EPC value. The energy or heat consumption reported in the EPCs is in average 12.5 kWh/m² higher than the values found in the documents in the building permit.
- The energy performance calculations are in several cases neither clear nor stringent. They often include a mix of values for energy performance with values for household energy and energy for other activities that are not included in the energy performance, so it is sometimes impossible to interpret the calculations.

The mean energy consumption according to the EPCs is close to those stipulated in the building code. So, in general the building code is fulfilled.

5.2.3 Why does the energy consumption differ between planned and built?

5.2.3.1 And do the calculation software packages have enough relevant data input to give a credible calculation, and if so, does the construction document provide sufficient information for implementation of the energy solution at site? What parameters or variables makes the calculation different from the outcome?

The question of whether the calculation programs have sufficient relevant data input to make a successful calculation could not be analysed in-depth. The building permit document provides some information but does not include the same information as the EPC document. These two data sets, the building permit and the EPC, should be consistent. When looking at documentation from the local city planning office, the author thinks the calculation from the client should follow some demand list or checklist that contains mandatory information. The author believe the lack of such a list is a problem.

Do the calculation softwares have enough relevant data input to give a credible calculation and if so, does the construction document provide sufficient information for implementation of the energy solution at site? What parameters or variables makes the calculation different from the outcome?

The question if the calculation programs have enough of relevant data input to do a successful calculation could not be analysed in depth. The building permit document provides some information but that does not include the same information as the EPC document. These two data sets should be consistent so when looking at documentation by the local city planning office the calculation should follow some demand list or checklist that contains mandatory information.

5.2.3.2 Are there other faults such as training, changes of the codes too often, lack of clear responsibilities, lack of testing and training, building processes?

The local city planning officials are responsible for the building permits and the nationwide the Swedish National Board of Housing, Building and Planning is a central government authority assorted under the Ministry of Enterprise and Innovation. It would be easier for consumers to understand the labelling and for authorities to supervise energy performance in newly built buildings if these municipal and governmental operations were able to coordinate the EPC in detail. This would increase the value significance of the calculation and the EPCs.

5.2.4 Are there any differences between owner type groups or calculation companies?

That could not be statistically proven because when the author includes the number of calculated values there are less difference between different owner´s types.

5.2.5 How can the practice about reduction of energy consumption be improved? What is important to consider when planning new buildings in Sweden?

It is the authors proposal that the planning phase calculations should be made available to be compared with measured values and the data from the calculation in the planning phase should be stored in a national database like the EPCs are in Gripen. Maybe a scheme, which would consist of a national calculation program for reassuring the accuracy of the calculations.

In the national wide database, it should be mandatory to store data about:

1. BBR references used
2. Area of the building and the area of any garage
3. Climate zone that are chosen for the calculation, there should also be a verification calculation of this
4. Ventilation flows
5. The household, operational energy the energy for heating energy for electricity etc.
6. Windows /doors and their U-values.
7. The energy source used.

This national database, with possible automated procedures, checklists and training for the calculation in the project phase and also the EPC would make it easier for the consumer to understand the labelling and for the authorities to supervise energy performance and an improvement for the environment and the CO_2 emissions. This would increase the value of the calculation and of the EPCs.

A consistent use of a special protocol for the calculations would probably improve the practice for energy calculations in the planning of buildings. In general, the author believes that focusing on the energy demand in the building code is a good idea for those buildings with minor internal loads such as dwellings. However, for commercial buildings as for example restaurants, server halls, sport facilities with various intern loads there should not be a focus on energy demand in building codes instead focus should be on the buildings as one unit and with special regard to anticipated internal loads. The EPC should offer an opportunity for follow-up on the planned energy performance.

The planning phase calculation should be made available for comparison with measured values and the data from the calculation in the planning phase should be stored in a national database like the EPCs are in national data base - Gripen. Perhaps such a scheme could consist of a national calculation program for reassuring the accuracy of the calculations.

One reason for this proposal is because this can be shown because it includes information that is already available.

6 Discussion

6.1 Introduction to discussion in Paper I

6.1.1 How the results have been cited by other researchers

This chapter discusses Paper I and its findings in relations to other research papers in the field. Particular attention is given to how these findings align with different insights in other studies. It is noteworthy that several researchers have cited this study as part of their analyses indicating that it already has contributed to the scientific discourse in this area of research. Below, the author discuss how some of those references position this study in relation to existing research, as well as the new perspectives and implication that can be drawn from the findings.

6.1.2 Studies that are similar to Paper I

In ref [17] Pagliaro et al. add information from Italy similar to what is given in Paper I, there are also similar studies from Ireland, Denmark, Italy, Sweden Portugal, Spain, Swiss and England, however the author lack a summary over these studies.

In ref [82] Droutsa et al. refer to baselines for energy use and carbon emission intensities in Hellenic non-residential buildings. This article refers to Paper I with more information than any other of the referents. They use the energy uses in each category, they also included studies done from the same purpose from other countries using EPCs.

6.1.3 Studies with similar results about schools or sports facilities

In ref [23] Attanasio et al. write “Toward an automated fast and interpretable estimation module of heating energy demand a datadriven approach exploding building EPCs”. That’s what Paper I shows that real energy consumption is often higher than the one stipulated in the building code.

In ref [24] Azaza et al. discusses energy flow mapping and key performance indicators for energy efficiency support. The study is about sports facilities. This article refers to Paper I in regard of energy consumption and also adds that this vary may vary strongly based on the type of sport facility. Noticeable is that in the conclusion they also write about how energy consumption strongly vary between months. It also states that area in combination with operation hours could diagnose the energy system in the building.

In reference [25] Ding et al. study energy profiles of schools in Norway. This study refers to Paper I and also to a study from Finland that conclude that the profile in energy use in schools is about the same in Norway as in Finland and Sweden.

6.1.4 Energy consumption in hotels

In ref [26] Amirkhan highlights the fact that due to shortcomings of the existing EPC framework the effectiveness of MEES (Minimum Energy Efficiency Standard) in reducing the CO_2 emissions from hotels is at risk. Unless these issues are rectified, actual contribution form MEES in the hotel sector may be considerably less than expected. The report refers to Paper I as it states that evidence from literature suggests that the levels tend to be beyond what can possible be condoned. However, this is a direct contradiction to what is stated in Paper I.

6.1.5 EPCs as a starting point for retrofits

In ref [27] Gangolells et al. discuss "LCA and cost-effective energy retrofitting of offices". They conclude that investment in heat pumps and LED lamps are the most efficient actions for energy renovation. As this study was done in Spain they also conclude that this renovation for energy efficiency also reduces emissions by 99, 5% during the life cycle. For heat pumps in Sweden, that may not always be the case as district heating, may have less carbon foot prints than heat pumps depending of the source of electricity for heat pumps.

In ref [28] Ruggeri et al. discuss "Energy retrofit in European building portfolio." They give a review of five key aspects. They state that for retrofit the house owner should make an assessment, choose a design, take a decision and allocate resources. It has an interesting description about segmentation of the energy efficiency on portfolio level. Paper I is quoted in the assessment segment.

In ref [29] Gouveia et al. discuss "Harvesting bid data from residential building EPCs: Retrofitting and climate change migration insights at a regional scale". They give an analysis of half a million EPCs for residential buildings in Portugal. These buildings are regarded to be energy efficient with potential for improvement of windows and roofs.

6.1.6 Energy performance and construction year

In Zhuravchaks et al." The effect of building attributes on the energy performance at a scale" [16] with the under title "an inferential analysis", the conclusion is that buildings constructed before 1990 in Norway have distinctly either high or low energy performance.

6.1.7 EPC and ventilation system and IEQ

In ref [30] Cabovská et al. study the relationship between energy performance and IEQ parameters in school buildings, see also ref [31]. They state that the relation to indoor climate is unknown. It is seen in data that Mandatory ventilation controls OVKs (obligatorisk ventilationskontroll) are not always properly performed. This article refers to Paper I as a reference that EPC´s can serve as an important instrument to promote energy efficiency in buildings, but can also be used as an power fool when analysing the building stock.

6.1.8 EPC presented in a map – on urban scale

In ref [32] Cerquitelli et al. present "A data-driven energy platform: from EPC to human readable knowledge through dynamic high resolutions geospatial mats". This gives a similar conclusion as in ref [18] but out of a different model.

In ref [33] Mutani, freely interpreted, states that EPC could be presented in urban scale as a GIS map that facilitates access to data and spatial representation of results.

6.1.9 Discussion on energy performance certificates in the future and are data in EPCs reliable?

In ref [34] Bienvenido-Huertas et al. refers to Paper I and state that the high building energy consumption is because of a deficient building stock. However, the author cannot agree with that statement. The building stock in Paper I is sufficiently big for the analyses. However, this article [34] states that cooling energy demand is increasing and heating energy demand is considerably reducing. And that means that climate zones are less effective to establish homogenous zones of building energy performance. This article [34] takes up a relevant question how energy performance could be more adapted to the needs for the future.

In ref [35] Bienvenido-Huertas, refer to Paper I as a mapping of a country's energy use. The articles entitled "Analysis of the impact of the user profile of HVAC systems" focuses mainly on cooling, but cooling is not the main point in Paper I. However, they mention the bias of regulation on a yearly demand, that greater cooling demand needs to go from a yearly base or to months to hours for making a comparison on energy demand.

In ref [36] Westermann et al. discuss "Surrogate modelling for sustainable building design - a review" – and states that there are mainly three types of data in the building domain, building sensors, building simulation data and building stock data as in Paper I. The paper is mainly a litterature review.

In ref [37] Pasichnyi et al. discuss "EPC- New opportunities for data –enabled urban energy policy instruments?" This paper concludes that overall, the broader scope and lager number of applications than were initially intended by the EPC policy instrument, increase its impact, but at the same time places stronger requirements on the quality and content of EPC data.

In ref [38] Fabbri et al. discuss "EPBD independent control system for EPCs: The Emilia –Romagna Region (Italy) - pioneering experience". In the conclusion a quality control campaign where 2% of the EPCs were checked on site. The results are that there are a majority who struggle with a number of difficulties of the profession as understanding legislation, impossibility to find data, lack of time and so on.

In ref [39] Mangold et al. discusses "Building ownership, renovation investments and energy performance- A study of multifamily dwellings in Gothenburg". The paper state that that both building ownership and socio–economic characteristics of the area where the building is situated are useful in explaining variation in energy performance. These findings are not concluded in Paper I.

Also, in ref [40] Andelkovic et al. bring up the relevance of EPC and energy savings. What they state about Paper I is hard to understand. The purpose of their article is, however, to determine the possible gap between the EPC and the real consumption in Serbia. When issuing an EPC, the national methodology only recognizes energy consumption for heating. The conclusion is that for district heating the EPCs are regarded reliable, but not for gas boilers, because for them energy consumption differs between 11 to 101 kWh/km^2. The article suggests that the EPC should also provide measured energy consumption.

In ref [78] Piscitelli et al. states that in Sweden the analysis of 186 021 EPCs for commercial buildings demonstrated the positive impact of stringent building codes on energy efficiency. This study [78] uses AI and has 47 000 buildings as a database.

6.1.10 Uncertainties in calculation tools or software –Paper II.

In reference [42] Amirkhani et al. focus on the real problem in the article named "Uncertainties in non-domestic (hotels) energy performance certificate". The study is done on UK buildings and concludes that the results differs depending on the calculation program and therefore connect to Paper II the author can agree on this for some of the buildings. The conclusion, however, is that EPCs are not reliable. But the author miss the word "when calculated" in that report.

In ref [43] by Gangolells et al. in "Energy benchmarking of existing office stock in Spain: Trends and drivers" is noticed how we, in Paper I, and Armitage et al. analysed in depth the final energy consumption of buildings in the office sector in respectively countries as Sweden and England. In the conclusions they mention ideas that can be important for the conclusion of EPC, namely that 66,9% of the EPCs studied contain non-reasonable information. They also suggest the implementation of consistency checks to reduce the possibility of errors of the EPCs, which the author also propose in Paper II. Energy for hot tap water was often estimated too high and energy for lighting was estimated too low. They conclude that EPCs provides a unique opportunity for long term monitoring of the building stock.

6.2 Introduction to the gap between the billed energy consumption and the energy displayed in the EPC

In several studies, such as Rosenberg et al. [44], the objective has been to evaluate how new buildings are designed, commissioned, and implemented in new buildings and how well they provide cost-effective energy savings. Studies have shown that demand for heating energy is the main reason for deviations between planned and real energy consumption. Similar studies have been conducted by the Swedish government through the Swedish Energy Agency, which has gathered information for multi-dwelling buildings and other facilities [46]. Recent studies by Borgstein et al. [47] stated that buildings regularly fail to perform at optimum levels and often do not meet performance stated in the design phase.

Pieter de Wildes study [48] discuss the gap between predicted and measured energy performance of buildings. That study stated that the gap in performance is a function of time and external conditions. It is written that this performance gap can only be bridged by a broad, coordinated approach that combines model validation and verification, improved data collection for predictions, better forecasting, and change of industry practice. This is only possible if the current practices in building engineering are changed.

However, energy policy fails to tackle the gap between the calculated consumption (that is, the anticipated or promised) and the actual consumption, Gram-Hanssen and Georg et al. [49]. Governmental policy has primarily focused on promoting the development of more energy-efficient initiatives, although these have often proven insufficient to meet climate targets. Further, they may even be counterproductive, because they normalize and stabilize certain levels of service without reducing energy demands [49].

In times of boom or very strong demand, and particularly when commercial properties are viewed primarily in terms of their investment value, developers tend to increase the number of specifications. Under these conditions, this is the case, for example, in the UK market, where ‘headquarter’ standards, including energy intensive technologies and full air conditioning have become the norm, as Guy and Shove have noted [50]. In times of recession, users have a greater influence on the design. Different countries have their own histories of property development, each associated with a different network of players and interests and each following its own temporal pattern. While technologies of energy efficiency might be 'transferable', in the rather abstract sense that similar measures could function effectively in different countries, it is a real sense in which unique socio commercial histories preclude any such simple 'transfer' as Shove writes [51].

6.2.1 Energy performance in Swedish building permits

In connection with technical consultation with the building permit official, the developer shall present an energy calculation that complies with the requirements of the Swedish building code (BBR). This is because the calculated energy performance is an important part of the building permits in Sweden.

The Swedish building code that governs the thermal performance of the building envelope was substantially changed, with stricter requirements, in 2006 [52], when energy performance started to be expressed in kWh/m^2 and the target for building code became the measured energy consumption during a 12-month period within two years after the building's initial occupancy. These new regulations in the building code started to influence buildings registered in 2010. Since 2010, the building code has gradually been changed further.

The building code indicates that energy calculations are needed in the building permit for new buildings. The code dictates how much energy consumption is allowed per heated square meter A-temp, the requirements for thermal insulation properties of the building envelope (U-value requirements), as well as specific requirements for houses where electricity is the main energy carrier for heating. During the technical consultation, the building permit officials check that the energy calculation is available. This is to be verified two years later with an energy performance certificate (EPC) based on the actual energy consumption. [54].

Paper II presents an analysis of data of new buildings in the city of Stockholm produced during the period 2010 to 2015. In this period, the urban planning has data for 93 buildings [54]. In the EPC data base of the Swedish National Board of Housing, Building and Planning (called Gripen) [5] , during the same period 227 buildings are recorded [55] and in the taxation register 693 buildings are filed [53]. Obviously, these three data sets relate to different numbers of buildings .

The taxation register includes all buildings that are there. Gripen include about a third of the buildings. The local municipal office of Stockholm provides information of about 14-15% , i.e., one building out of seven.

Paper II presents a comparative investigation of new commercial buildings in Sweden.

Consistent use of a special protocol for the calculations would probably improve the practice for energy calculations in the planning of buildings. In general, the author believes that focusing on the energy demand in the building code is a good idea for those buildings with minor internal loads, such as dwellings. However, for commercial buildings with various internal loads, such as restaurants, server halls and sporting facilities, the should be an exception to the building codes.

Zuhaib et al. [56] in "Next generation EPCs End user needs and expectations" state that 6 million residential EPCs are issued every year in EU member states. This paper takes the end user perspective. It is written that the current EPCs have not been tailored to the needs of the end-users. The end-users are interviewed on line and feedback on the real energy consumption is perceived as more useful when it provides a comparison with the previous year than with similar households. The EPC databases would be more valuable if they presented the energy efficiency score of similar properties instead of giving a comparison with all properties. The information about costs has the highest informative value. The willingness to pay for the EPC is low.

Seduikytes et al. in [57] in the article “Next generation Energy Performance Certificates, What novel implementation do we need?” suggest to include SRI (Smart Readiness Indicator), human comfort indicators, LCA and financial schemes. They also argue for BIM information as a digital twin of the building.

Cebrat et al. [58] have presented the article “Assessment of Use Cases Involving data from energy performance certification process for buildings – From individual buildings to regain Scale.” They make about the same conclusions as in Paper II, that drafts of the coming EPC should be available from the first phase of the building development and implemented in schemes where building codes are checked from that data by authorities.

6.3 Visualization of questions

The question is how we can get a sustainable and predictable energy use in the building and a label that the user of the building can be interpret? The current label looks like this:

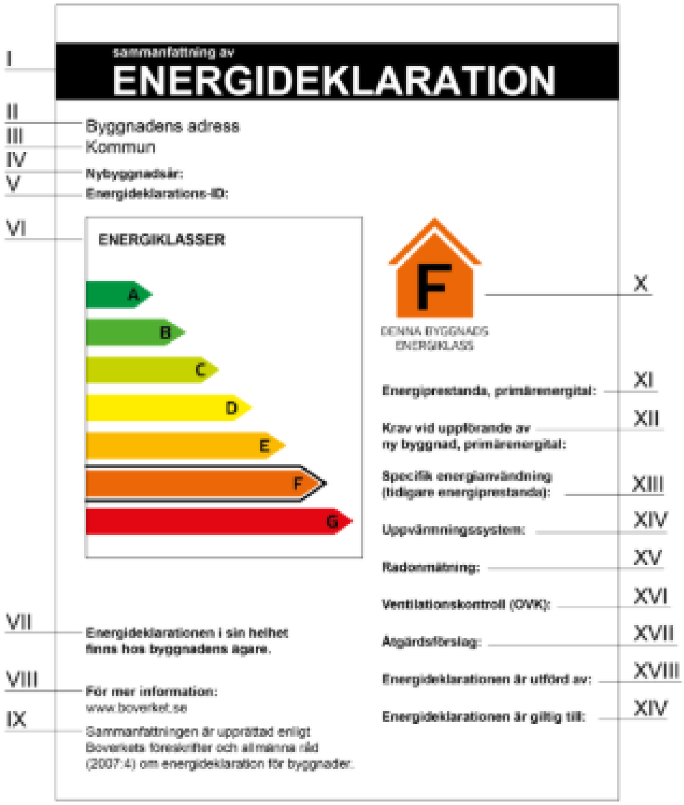

Figure 3*) Illustration EPC [77] Summary of the energy declaration after 1 January 2019.*

Property owners or developers can be tempted to influence the regulations, the experts and the designers of new buildings to understate energy consumption of new buildings. This can be because of business reasons, financial or policy reasons or for regulatory alignment. However instead of fooling the system and driving consultants in trying to manipulate the system they should seriously try to reduce energy consumption where it is necessary and make the labels understandable for new tenants.

After the EPCs were first introduced some changes have been done some for the bad and some fore the good. For example, the labels are more easily understood but the facts which are the base for the labels have drifted further away from the reality when they are based on calculations instead of energy measurements.

However, the EPCs were supposed to provide users of buildings with reliable information about buildings in order to motivate for improvement of buildings and to give the basis for a rational pricing process of a built assess.

Therefore, there would be of importance to make the EPCs user-friendly and reliable all over Europe.

Gram-Hanssen et al. [59] asked the question; "Do homeowners use energy labels? A comparison between Denmark and Belgium." That paper states that the idea of households as rational economical actors who will renovate their homes in an energy efficient way if they are just given the right knowledge has to be abandoned. This , however, not mean that the energy labels on buildings are a bad idea but they should be seen as one input among others to improve people's own knowledge and communication about their house and its renovation. Gram-Hanssen recommend that the focus on payback time be toned down and substituted by information on cost of investment and possible savings, to let people judge themselves.

According to the Swedish National Audit Office's audit report (RiR 2021:21) [60], the recommended energy efficiency measures are rarely implemented by homeowners, nor do they seem to affect private individuals' choices when buying a house, although they can affect its price by about 10–11%.

6.3.1 Related to previous research

Compared to results other research, what has these studies added?

1) For Paper I there are similarities with the results found for Greece [22] and Spain [45]. Our results are based on the first round of energy certificates in Sweden and also the role of changes in the building code.Pursuant to the research questions, the purpose of this research project is to contribute to the process of suggesting actions to develop the labelling of commercial buildings. This study provides an understanding about the status of the Swedish building stock and also conveys valuable insights about the potential for energy improvements. Similar studies have been conducted previously for Spain [45], Greece [22] , and Italy [17][38]. A review of the data, published by the Swedish Energy Agency, gives an insight in to the levels of energy for commercial buildings, consisting of multi-dwelling buildings, rental premises mainly offices, schools, healthcare facilities, sport facilities and hotels and restaurant. As a reference and validation of the results, data [61] and [62], based on answers to a questionnaire are compared to some of the results from this database. The research article has had an impact on the field , as reflected in a large number of citations of the article during 2025 for example [63], [64], [65] and [66].

2) Looking at Paper II and comparing the actual energy consumption with what was planned and what was built. There are several similar studies done. Actually the EPCs are that in their self. However, one of the most interesting articles [76] provides visualising of their theorise and the term -The Energy Performance Gap, EPG, generally defined as the difference between expected energy consumption calculated by a building performance assessment and the actual consumption. The gap consist of actual deviation as malfunction equipment, measurement system limitation, execution of the work, Non-optimal use of the building by the occupant, and the theoretical deviations as inaccuracy of occupant behaviour modelling, inaccuracy of inputs and assumptions for building modelling and inaccuracy of climate data [76].

The total energy use are also figured [76] as consisting of EPBD regulated loads, Procurement gap, Occupant behaviour, non-regulated end use, Inefficiencies and uncertainties and special functions. Building energy performance measurement and verification plan, as discussed by Burman et al. [79]. Causes for the performance gap between design phase predictions and measurements of energy use in the building's operational phase are presented by Stolterman in her thesis [80]. These are shown in Figure 3.

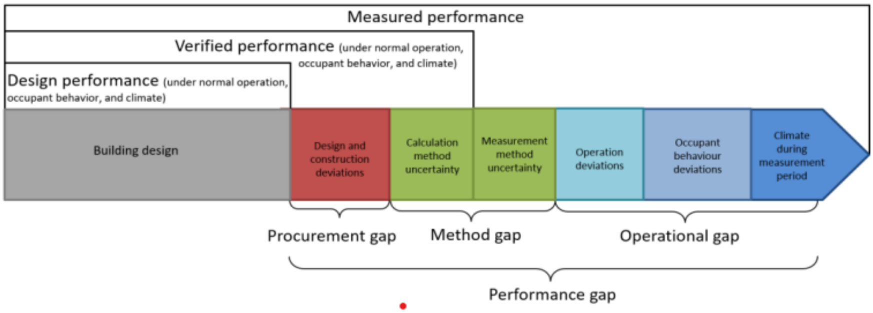

Figure 4) Stolterman figure - Causes for the performance gap between design phase predictions and measurements of energy use in the building's operational phase [80].

There is an interest of economy and also carbon dioxide emissions that's why you want to compare buildings for rent or purchasing. In ref [67] Jonkutè et al. presents an analysis of carbon dioxide emissions in residential buildings through EPCs in Lithuania. Lithuania has a different situation with more gas-boilers, that are almost non existing in Sweden. The conclusion is that the buildings with energy class G emits more CO_2 than those with energy class A.

Fabbri et al. [81] discuss whether the EPC of the building can be useful in the reduction of fuel poverty. The conclusion in the end says that EPCs could be used as tools for the analysis of the housing stock as "Fuel poverty evaluation tools". Then the importance in involving the occupants and also analysing more parameters in the chart such as operational energy.

Belussi et al. [68] discuss "Simplified tool for the EPC assessment of residential buildings". It states, if the author interpret it correctly, that EPCs are relatively correct and are a stimulus for a growing awareness of energy and environmental issues, expect for Italy where national regulations provides simplified methodologies.

6.3.2 What is happening now in the field of interest- Legislation?

Implementation of the building rules called " Möjligheternas Byggregler" translated the possibility of rules in June 2023 [69].

There are new EU-regulation where The Commission proposes that the concept of zero-emission should building be introduced. -production of renewable energy on site, renewable energy from a local energy community or through locally produced renewable district heating/district cooling [70], [71].

The proposal contains increased requirements for data collection and information exchange between actors, the member states and the EU, among other things in the form of requirements for a national database for information on the energy performance of buildings and increased accessibility to data from the various control systems of buildings [71].

The interpretation in Finland about the new regulations [75] and the conclusions are:

The Government considers it extremely important to ensure that the proposal does not increase the administrative burden unnecessarily. Any administrative burden must be proportionate to the added value it provides.

7 Conclusions

7.1 The most important results in Paper I and Paper II

1. There are difference in consumption, the building code does matter. The subdivision of the Swedish climate zones has less impact on energy consumption than type of building
2. Looking at the building category in, and then especially at multi-dwelling buildings (which are in the majority with 127,725 certificates and a total of 217.8 Mm^2), these labelled buildings have an average energy consumption of 145 kWh/m^2. The building types with less energy consumed on average are factories and rental premises, mainly offices. The highest energy consumption on average is for hotels and restaurants and for sports facilities.
3. Looking and comparing the actual energy consumption with what was planned and what was built. For buildings with submited documents the mean energy consumption according to the EPCs is close to what has been requested in the building code. So, in general, the building code is fulfilled. However, documentation for several buildings is missing at the time they should have been subimitted.

The labelling for commercial buildings is hard for a third party to decipher as it is hard even for those working in the field. And the use of factors is making the labels theoretical.

Area is the most prominent factor for the EPG difference. The results may in reach be considered as practical application that the building regulators must be observant of the area of the building in the building permit. Also, the results in Paper I are strictly deponent on Area.

To summarize the core and to relate to the purpose and the research questions: Our main findings are that the area and the type of building are not registered in a reliable way, and also may change during the planning and development.

8 Further research and the future

Future studies could be performed on labelling risk estimation, which risks could be identified with the labelling of the different objects? In real estate, there are substantial values involved. What risk estimation can build labelling provide? Who would we influence the future?

The AI revolution would make it simpler to collect and analyse data. The regulation gets stricter and the steps between the regulators in EU and different levels of subcontractors becomes even bigger.

Building on the key findings presented above, the author suggest for future research, the influence of building type on the energy performance, the role of floor area and an in- depth analysis of residential buildings, which constitute the largest segment of the buildings stock. Furthermore, it would be interesting to investigate the underlying reasons for delays in submitting energy performance certificates (EPC´s).

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