MASTER'S THESIS

Impact of Energy Performance Regulations on HVAC Innovation

Adressing the Characteristics of French and Swedish Regulations

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Foreword

This thesis was written between June 2014 and February 2015 as the last part of the Architectural Engineering program at Luleå Tekniska Universitet. For me it marks the end of a 10 year journey that has taken me from Luleå to the US and France, back to Luleå and now finally to Stockholm. I've had the privilege of studying in different countries and meeting a lot of wonderful and inspirational people, many of whom have contributed to me (almost) having an MSc in engineering.

I would like to thank Bernard Avallet at Swegon in France for hiring me in 2012 and giving me the opportunity to work with the subjects that this thesis is about. I would also like to thank John Woollett at Swegon, for taking the time to guide me in this process and helping me out when it was time for me to come home to Sweden for the Swedish part of the study. Thanks to Susanne Engström for being my tutor at the university, and giving me feedback and suggestions on how to improve my work.

Last, but definitely not least, I would like to thank my mother for always being there to encourage me, answer questions and give advice. I could not (and would not) have done this without you.

Lydia Karlefors
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Abstract

Buildings are responsible for 40% of the energy consumption in the EU, and a reduction of the energy consumption of buildings is considered necessary by the EU in order to reach its energy saving goals. One of the actions taken is the adoption of the Energy Performance of Buildings Directive (EPBD) that is implemented in the member states' national Energy Performance (EP) regulations. Since innovation can contribute to better energy performance of buildings, it is important that EP regulations do not become a barrier to innovation. The EU wants to encourage innovation, but there is a lack of systematic evaluation on how EP regulations impact innovation. The purpose of this thesis is to contribute to a better understanding of the impact of EP regulations on innovation in the HVAC sector. A more specific aim is to compare the EP regulations in two EU member states and discuss the expected impact of the regulations on innovation based on five specific characteristics. The selection of the compared member states France and Sweden is justified by on-the-job observations indicating differences between their respective EP regulations. The theoretical framework for this thesis shows that the impact of regulation on innovation is largely dependent on how the regulation is designed, with specific regulation design characteristics being relevant for the impact on innovation. Five characteristics, namely: stringency, flexibility, certainty, transparency and enforcement, were included in the analysis model presented in this thesis and used to analyze the qualitative data. Data was collected through semi-structured interviews with professionals in France and Sweden and a desk study.

The results suggest that the EP requirements of French regulation are stringent, which according to the theoretical framework can be expected to drive innovation. The French approach with using a complex regulatory calculation method for calculating a building's EP is considered to imply less flexibility and freedom for innovation. The complexity of the calculation method can lead to less transparency, which according to the theoretical framework can have a negative impact on innovation. France has already presented future EP requirements. The increased certainty can be expected to increase firms' innovative ambition. If enforcement is weak, the regulation is not to be expected to drive innovation. Few new buildings are checked for compliance in France but there are penalties for non-compliance. The Swedish EP regulation is considered less stringent, but the Swedish approach with compliance based on measured energy use of a finished building implies high flexibility and transparency. In Sweden the future requirement levels have not yet been presented which can create uncertainty. There is a risk that compliance falls between the jurisdictions of national authorities that define the requirements and local authorities are responsible for enforcing them. The French EP regulation, with high stringency, certainty and enforcement but less transparency and flexibility than the Swedish, is expected to have a stronger impact on HVAC innovation. The French regulation can be a driver to HVAC innovation that is adapted to the regulation, but risks becoming a barrier to innovations that are not included in the regulatory EP calculation method. There seems to be both advantages and disadvantages with the Swedish EP regulation from an innovation perspective, depending on which characteristics are considered. Based on the results of this thesis one cannot state that the Swedish EP regulation drives or hinders innovation in the HVAC sector.

Sammanfattning

Byggnader står för 40 % av energianvändningen inom EU. För att EU ska nå sina uppsatta miljömål behöver energianvändningen i byggnader minskas. Nationella energiprestandalagstiftningar (EP-lagstiftningar) är ett resultat av genomförandet av Direktivet om byggnaders energiprestanda (EPBD) som antogs av EU för att minska energianvändningen i byggnader. Innovation kan bidra till att förbättra byggnaders energiprestanda, varför det är viktigt att EP-lagstiftningar inte hindrar innovation. EU vill främja innovation, men det finns en brist på systematisk utvärdering om påverkan av EP-lagstiftningar på innovation. Syftet med detta examensarbete är att bidra till en bättre förståelse av hur EP-lagstiftningar påverkar innovation i HVAC-sektorn. Ett mer specifikt mål är att jämföra två EU-länder och diskutera den förväntade effekten av EP-lagstiftningarna på innovation utifrån hur lagstiftningen är utformad med fokus på specifika egenskaper. Tidigare arbetslivserfarenhet av EP-lagstiftningar i Frankrike och Sverige motiverade valet av länder.

Det teoretiska ramverket för detta examensarbete visar att den inverkan en lagstiftning har på innovation i hög grad beror på hur lagstiftningen är utformad. Fem egenskaper; stränghet (stringency), flexibilitet (flexibility), visshet (certainty), transparens (transparency) och genomdrivande (enforcement), bildade den analysmodell som användes för att analysera kvalitativa data. Data samlades in genom semistrukturerade intervjuer med yrkesverksamma i Frankrike och Sverige och en skrivbordsstudie.

Resultatet av detta arbete antyder att EP-kraven i den franska lagstiftningen är stränga (stringent), vilket enligt det teoretiska ramverket kan förväntas främja innovation. Den franska strategin att använda en komplex beräkningsmetod för att beräkna en byggnads energiprestanda bedöms innebära mindre flexibilitet och frihet för innovation. Beräkningsmetodens komplexitet och omfattning kan leda till mindre transparens (transparency), vilket enligt det teoretiska ramverket förväntas ha en negativ inverkan på innovation. Frankrike har redan definierat de framtida kravnivåerna för byggnaders EP vilket ökar vissheten (certainty) för företag och kan förväntas öka deras innovativa ambition. Om lagstiftningen inte genomdrivs, bör den inte förväntas driva innovation. Få nya byggnader kontrolleras i Frankrike varje år, men det finns påföljder för bristande efterlevnad (enforcement). Den svenska lagstiftningen visade tecken på att vara mindre sträng (less stringent), men strategin med att mäta energianvändningen av en färdig byggnad antyder större flexibilitet och kan även anses vara transparent. I Sverige har de kommande kravnivåerna ännu inte presenterats vilket kan skapa osäkerhet (uncertainty) och det finns även risk för bristande kontroller eftersom att det är nationella myndigheter som ställer kraven och lokala myndigheter som ska kontrollera att de efterlevs (enforcement). Den franska EP-lagstiftningen, som anses vara mindre flexibel och transparent än den svenska förväntas ha en starkare inverkan på innovation inom HVAC. Den kan driva innovation som är anpassad till lagstiftningen men riskerar att bli ett hinder för innovationer som inte är inkluderade i beräkningsmetoden. Det verkar som att det finns fördelar och nackdelar med den svenska EP-lagstiftningen, beroende på vilken egenskap som studeras. Från resultaten av detta

examensarbete kan man inte hävda att den svenska EP-lagstiftningen driver eller hindrar innovation.

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Terms and abbreviations

AHU - Air Handling Unit

ASIEPI - ASsessment and Improvement of the EPBD Impact

BBC - Batiment Basse Consommation, French label for low energy buildings

BBR - Boverkets Byggregler, the Swedish technical building rules with a section on energy management including the Swedish EP regulation

COP - Coefficient of Performance

CSTB - Centre Scientifique et Technique du Batiment

DHW - Domestic Hot Water

EP - Energy Performance

EPB - Energy Performance of Building

EPBD - Energy Performance of Buildings Directive

HVAC - Heating, Ventilation and Air Conditioning

IEA - International Energy Agency

nZEB - nearly Zero Energy Buildings

R&D - Research & Development

RT 2012 - Réglementation Thermique, the French EP regulation

SVEBY - Standardize and verify the energy performance of buildings

TEBUC - Towards an European Building code

Th-BCE - The calculation method for the French EP regulation

Titre V - Alternative assessment procedure for innovations in French EP regulation

1. Introduction

In this chapter the background of the subject of study for this thesis is presented, along with a short presentation of the problem, purpose of the thesis and research questions. In the introduction chapter there is also a schematic overview of the research questions and definition of the delimitations for this thesis.

1.1. Background

The introduction of new products to the marketplace is essential for the success of a company (Fahy & Jobber, 2012). In the European Union (EU) there is an ambition of encouraging innovation and there are also many regulations in place that affect every step of the innovation process (Pelkmans & Renda, 2014). Whether standards and regulations encourage or hinder innovation has been the subject of debate in the research community (Ortt & Egyedi, 2013). The idea that the impact of the regulation on innovation depends on how the regulation is designed and that specific regulation design characteristics are relevant for the impact of a regulation on innovation is presented in multiple studies (Porter & van der Linde, 1995; Rothwell, 1992; Johnstone, Hascic & Kalamova, 2010).

Regulations are a powerful tool used by governments when market forces are not powerful enough to create a situation that is optimal for society (Pelkmans & Renda, 2014), such as reducing the energy consumed by buildings through improving their energy performance. Buildings are responsible for 40% of the total energy consumption and more than 30% of the CO_2 emissions in the EU (van Dijk & Spiekman, 2004). The EU considers a reduction in the energy consumption of buildings necessary in order to honor its environmental commitments and reach its energy saving goals. One of the actions taken in order to reduce the energy consumption of buildings is the adoption of the Energy Performance of Buildings Directive (EPBD) in 2002 (European Commission, 2010). The implementation of the EPBD requires the EU member states to set quantitative limits for the energy consumption of buildings and to define how the energy performance of a building should be calculated. These requirements are transposed into national building regulations, referred to as energy performance (EP) regulations. The EPBD defines a final objective that is to be achieved by the member states, but leaves it up to the national authorities to decide how the objective should be reached and design the regulation accordingly (European Law Monitor, n.d.).

In terms of energy use in buildings, HVAC (heating, ventilation and air conditioning) systems account for half of the energy consumption of buildings in developed countries (Pérez-Lombard, Ortiz, Coronel & Maestre, 2008). Therefore, finding viable ways to reduce the energy of HVAC systems is essential in order to reduce the total energy consumption of buildings. Important improvements in the energy performance of buildings can be obtained using existing technologies, but innovation can allow for further improvements or achieve the same improvements in a more cost-effective way (ENPER, 2003). Promoting technological innovation can contribute to more energy efficient buildings (Noailly & Batrakova, 2010) and may even be necessary in order to reach the objectives of reducing their energy consumption (Spiekman, Heijmans, Wouters & Caillou, 2010). It is therefore of high importance that building regulations aiming at improving the energy performance of buildings do not become a barrier to innovation (Spiekman et al. 2010).

1.2. Problem

Since the EPBD only sets a final objective, there are differences between member states in terms of EP regulation design (van Dijk & Spiekman, 2004) and approach to innovative products and systems (Heijmans, Wouters & Loncour, 2008). The main objective of the EP regulations is to reduce the energy consumption of buildings. The impact of the regulations on innovation is described by Beerepoot (2007) as a side effect that research has dedicated little attention to so far. In order to not close the door to potential energy savings, energy performance regulations should encourage, or at least not hinder, innovation (Spiekman et al., 2010). The lack of previous research on the impact of EP regulations on innovation can make it more difficult for the lawmakers to design regulations that reach the environmental goals while having a positive impact on innovation, since prior research on the industrial response to regulations usually serve as a base for regulatory strategies (Ashford, Ayers & Stone, 1985). Innovative firms risk being faced with building regulations designed in a way that they pose a barrier to the market uptake of innovative energy efficient concepts (Heijmans et al., 2008).

1.3. Purpose of the thesis

The overall purpose of this thesis is to contribute to a better understanding of the impact of EP regulations on innovation in the HVAC sector. A more specific aim is to compare and contrast EP regulations in two EU member states and discuss the expected impact of the regulations on innovation based on specific regulation design characteristics. The main research question is:

- *How can the design of the French and Swedish energy performance regulations be expected to impact innovation in the HVAC field?*

The specific choice of focusing on the EP regulations in France and Sweden is based on previous work experience of issues related to innovations and EP regulation for the French subsidiary of a Swedish HVAC company. On-the-job observations suggested that EP regulations could pose a barrier to the introduction of an innovative product to the market in a country other than the one where it was developed, where a different regulatory framework is in effect. The previous work experience also indicated that Sweden and France have taken diametrically different approaches to the adaptation of the EPBD in their national building EP regulations. These differences in approach make France and Sweden a relevant choice for comparing and contrasting EP regulations, characteristics of EP regulation design and subsequent impact on innovation in the HVAC sector.

To address the aim of the thesis and answer the main research question it was necessary to first establish how the impact of regulation on innovation has previously been understood, by reviewing literature of existing research addressing the relationship between regulation and innovation. To further guide the literature review, the following two questions were formulated:

- *How can regulation impact innovation?*
- *What regulation design characteristics are relevant for the impact on innovation?*

The figure below (Figure 1.) shows a schematic overview of the thesis work. Due to the lack of previous research on the impact of EP regulations on innovation, the literature search was broadened to include environmental policy and regulation in general. The results of this literature review provided a theoretical framework covering how regulation can impact innovation. An analysis model was developed from the theoretical framework and specified five regulation design characteristics, stringency, flexibility, certainty, transparency and enforcement, which were considered important for the impact on innovation. Data was collected through semi-structured interviews with professionals in France and Sweden with experience of the EP regulation and a desk study based on information available online, mainly on authority websites and online HVAC journals. The results from the desk study and interviews in France and Sweden were then analyzed using the aforementioned analysis model.

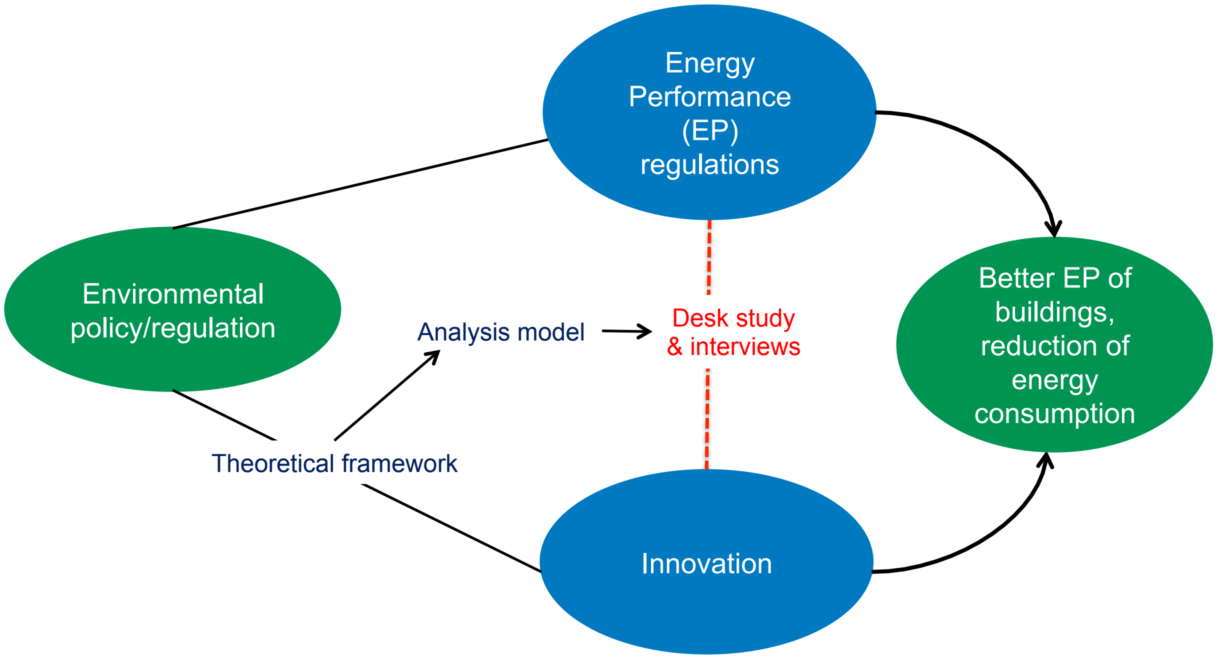

Figure 1. Schematic overview of the thesis work

1.4. Delimitations

For this thesis, only the effects of the EPBD requirements that oblige member states to set minimum requirements and develop a calculation method for the energy performance of buildings are considered. The EPBD also sets out requirements concerning energy certification of buildings, inspection of heating and air-conditioning systems and control systems for energy performance certificate and inspection reports but the impact of these requirements are outside the scope of this thesis. Evaluating if the EP regulations in France and

Sweden are successful in reducing the energy consumed by buildings is not part of the purpose for this thesis and is not discussed to any further extent. Other policy instruments or market factors that can impact innovation besides regulation are not taken into account.

There are differences between two countries regarding what authority is in charge of the EP regulation, how the legislative texts are written and what juridical power they have. This is not taken into account in this thesis work.

2. Methodology

In this chapter, the methodology of the thesis is described from a more abstract level down to concrete actions. The methodological choices are justified and the methods of data collection and analysis are presented.

2.1. Research pyramid

Jonker and Pennink (2009) have defined a “research pyramid” with four different action levels; paradigm, methodology, methods and techniques.

This model was used to design and guide the research process from a more abstract level down to more concrete actions. In short, the levels can be described as follows:

- Paradigm: the basic approach for the research, based on the way the researchers regard reality including their values, assumptions and premises.
- Methodology: the way that the research is to be executed, based on the research paradigm
- Methods: specific phases that are to take place in a certain order
- Techniques: practical means of generating, registering, classifying and analyzing data.

2.2. Paradigm

Enveloping the research methodology and methods is the general approach that will impact the research design on all levels, from the attitude and mindset of the researcher down to how interview questions are worded (Jonker & Pennink, 2009). According to Kothari (2004) there are two main approaches to research: quantitative and qualitative. The qualitative approach is useful when the objective is to gain a more in-depth understanding of attitudes, opinions and behavior (Jonker & Pennink, 2009).

For this thesis, a qualitative approach was used. The choice of approach is related to the purpose of the study, contributing to a better understanding of the impact of EP regulations on HVAC innovation by comparing EP regulations in two EU member states and their expected impact on HVAC innovation. The qualitative approach is relevant in order to gain an insight on how different actors perceive the impact on HVAC innovation of the EP regulation in their country. Another reason for the qualitative approach it that both regulation and innovation are complex concepts and difficult to quantify (Kemp, Smith., & Becher, 2000). Attempting to perform a quantitative study on the relationship between regulation and innovation, two complex concepts that are difficult to quantify, would give results with low validity.

According to Jonker and Pennink (2009), a qualitative research paradigm means that the researcher needs to see through the eyes of someone else in order to gain knowledge about reality. This can be compared with the quantitative approach, where it is believed that knowledge can be obtained by viewing reality through the eyes of the researcher. In this thesis work, the qualitative interviews made it possible to gain knowledge about the studied subject through the experiences of someone else (the interviewees). The desk study made it possible to take part in the opinions and experiences of more actors in addition to those interviewed, through information published on the internet. The qualitative approach is further defined by the role of the researcher: in quantitative research the researcher is considered to be an expert, whereas in qualitative research the researcher is viewed as an explorer, and cannot be an objective outsider (Jonker & Pennink, 2009). This is especially applicable to this thesis, where the researcher has previous experience on the subject of study and continued to work on subjects related to innovative HVAC products and EP regulation while working on this thesis. There is a risk of preconceptions that could affect the results of the thesis, especially concerning the impact of the French EP regulation on innovative HVAC products. This risk was taken into account in the design of the research methodology and contributed to the choice of using two data collection methods.

The qualitative research approach implies that the research is done on the basis of an inductive empirical cycle, where the research results in new theories instead of rejecting/confirming already existing theories as is done in a deductive study (Jonker & Pennink, 2009). Induction and deduction are opposites, where induction is generally described as "theory generating" where the empiric data in the study is used to generate theories that can be applied generally (Jakobsson, 2011). According to Backman (2008), an inductive research approach implies starting with data collection and after that (or simultaneously) developing hypotheses and theories. The approach used for this project could be defined as a combination of an inductive and deductive approach since some theories and opinions on how an EP regulation can impact HVAC innovation had already been formed during the researcher's previous work experience on the subject. This combination of the two approaches, which resembles the approach of this thesis work, is defined by Jakobsson (2011) as an abductive approach.

Qualitative research is also associated with an open unstructured research design, where phases of the research are related to each other in a cyclic and not linear manner (Jonker and Pennink, 2009). The qualitative research process is more dynamic and flexible than quantitative research, and at times different phases are in process at the same time and cannot be distinguished from one another (Backman, 2008). For this thesis, partly due to the complexity of regulation and innovation and the lack of previous research, the process has not been linear. Some phases such as work with the literature review, data collection and development of the analysis model could take place simultaneously. Sometimes information and knowledge from a later phase contributed to clarifying questions raised or uncertainties from an earlier phase, which led to modifications of earlier work throughout the process.

2.3. Methodology

The research methodology supplies the main outline on what has to be done in order to achieve a specific goal, without defining every specific action of the process (Jonker & Pennink, 2009). Since qualitative studies involve focusing the research on cultural and situational aspects of a phenomenon rather than the hard, technical aspects (Kvale & Brinkmann, 2009) interviews with open questions were chosen as a method of gathering empiric data for this thesis. The open questions allowed for the interviewees to express their opinions and share their experiences using their own words (Jonker & Pennink, 2009). According to Svenning (2000) one of the main dangers with qualitative analyses is that the thoughts and opinions expressed by the interviewees are seen as reality, and the analysis of the researcher is diminished. To avoid this, a desk study was performed as a second method to generate data about the EP regulations in France and Sweden. The data from the two sources were joined in the analysis in order to provide a fuller picture of the studied subject (Patel & Davidson, 2003). The use of multiple data sources for the purpose of increasing the reliability of the results as well as verifying their validity can be referred to as triangulation. Reliability refers to whether the chosen method of measuring will give the same results if the study is repeated and validity to whether the chosen method actually measures what it is intended to measure. (Jonker & Pennink, 2009) The research design for this thesis involved making choices that could have an impact on the results, such as the selection of the five regulation characteristics deemed relevant for the impact on innovation. However, if the work was repeated using the same theoretical framework and analysis model, it is likely that the conclusions would be similar to those in this thesis. If, on the other hand, a different theoretical framework was considered it is more likely that the conclusions would differ from those of this thesis work. In terms of validity and in relation to the purpose of the study, the chosen methodology is considered to have high validity. A quantitative study, trying to measure and quantify two complex concepts (regulation and innovation) would most likely result in a study with low validity.

The choice of methodology for this thesis was based on the understanding that it is important to distinguish between questions that can be answered by the desk study, i.e. through secondary research and questions that can only be answered through primary research (empirical research) (Randolph, 2009). In order to properly answer the research questions, it was necessary to get the point of view of selected professionals working in the field through interviews since they possess knowledge and have experiences related to EP regulations and innovation that have not been documented in written form, but also to make use of information available online. The results from the desk study and the interviews are considered to complete each other.

The choice of including France and Sweden was a natural selection based on previous work experience and proficiency in the languages spoken in the two countries which made it possible to conduct interviews in the interviewees' maternal language and read documents written in both French and Swedish. On-the-job observations of important differences in EP regulation between the two countries also made it possible to justify the selection of the two countries.

2.4. Methods and techniques

2.4.1. Literature review

According to Randolph (2009), writing a literature review fills multiple purposes: The literature review introduces the researcher to the existing research in the field of study, provides the researcher with an opportunity to demonstrate their knowledge about the studied subject and is a publishable scholarly document. In this thesis, the work with the literature review gave an opportunity to understand how earlier research regarded the relationship between regulation and innovation from a scientific point of view. It also served as a theoretical framework from which the analysis model, used to analyze the data from the interviews and the desk study, was developed. This concurs with Randolph (2009) who stated that writing a literature review can be useful because it can serve as a base for a framework that makes it possible to link new results with existing research in the field of study.

As previously mentioned, very little scientific research has been conducted on the subject of EP regulations and their impact on innovation (Beerepoot, 2007). A recent paper by Pelkmans and Renda (2014) concluded that even though the EU is concerned with increasing innovation; there has been little systematic analysis of how EU regulations impact innovation. According to Knopf (2006) the lack of previous research is common for research on recent topics and events, and in order to find sources for the literature review the researcher has to broaden the review and use sources that are relevant to only some parts of the research questions. For this thesis, the literature search for scientific articles using the key word "innovation" combined with "building regulation", "energy performance regulation" or "energy regulation" gave few relevant results. Adding the key word "HVAC" resulted in even fewer relevant results. The literature review for the theoretical framework was therefore broadened to include key words such as "policy", "environmental policy", "eco-innovation" and "standards". Most of the scientific articles and books used for this thesis were found using the databases Google Scholar, Science Direct and Primo.

Previous research on regulation and innovation has covered different industrial sectors and areas, and drawn conclusions about how the regulation impacts innovation in different cases (for example Ashford, Ayers & Stone,1985; Bergek & Berggren, 2014; Johnstone, Hascic & Kalamova, 2010). For the purpose of this thesis, it is assumed that conclusions concerning the impact of regulations/policies/standards on innovation in other sectors than energy performance of buildings can be transposed and can be considered valid for the case of EP regulations and innovation in the HVAC sector. In the studies included in the theoretical framework, some authors used terms such as "elements" (Ashford et al. 1985), "features" and "aspects" (Kemp & Pontoglio, 2011) to describe what is generally referred to as "characteristics" in this thesis. Based on the context in which they appear, the terms are considered to be interchangeable. For simplicity and coherency, the term "characteristics" is used throughout this report unless referring to previous studies where other terms were used.

Originally, the purpose of the literature review was only to present a review of previous research on the relationship between regulation and innovation. EU-financed projects studying the impact of EP regulations on innovation were supposed to be used to assess the French and Swedish EP regulations from an innovation perspective. These projects are presented in section 3.2. and provide a background to what has already been studied in the field of EP regulations and innovation. The results of the EU-financed project could only be used for a part of this thesis. It seemed as though the impact of the EP regulations on innovation was assessed assuming that compliance with the EP regulation was based on values calculated using a specific regulatory calculation method. Since compliance with the EP regulation in Sweden is based on measured and not calculated values, it was necessary to look further in order to find a way to compare the impact on innovation of EP regulations in France and Sweden. The idea of choosing specific regulation design characteristics having an impact on innovation for the analysis model was discovered during the work with the theoretical framework and the review of literature. The results of the literature review are presented in chapter 3: “Theory”.

2.4.2. Desk study

Cambridge Dictionaries Online defines desk research as *“a type of market research that involves collecting and examining information that already exists and is easy to get, such as company records, published government reports, and information in newspapers, magazines and on the internet”* (Desk research, 2015).

The two data collection methods, desk study and interviews, complete each other in a way that fulfills the purpose of the thesis. The desk study contributed to the purpose of the study by providing information that is available in written form that the interviewees may not know of and provide a general overview of the EP regulations in Sweden and France from a more “official” point of view than in the interviews since much of the information for the desk study came from government websites. The desk study also made it possible to take part in the opinions of multiple actors in the construction sector on certain aspects of the EP regulation in their country without interviewing them.

Some scientific articles were used for the desk study, but mainly reports from EU projects, official government legislative texts, information and reports from government websites and articles from online journals in the HVAC field. The internet provides a large amount of data related to EP regulations. The data for the desk study was selected based on its relevance in relation to the theoretical framework. The information that was originally in French or Swedish was translated by the researcher into English.

The labels of classification for the data gathered in the desk study were defined with the purpose of providing clarity and an overview of the EP regulation in France and Sweden and including information useful for the analysis using the theoretical framework. The same labels were used for both countries.

The results of the desk study are presented in section 4.1. “Results of desk study”.

2.4.3. Interviews

Interviews are often distinguished by their level of structure, and divided into three categories: unstructured interviews, semi-structured interviews and structured interviews. But as Brinkmann (2013) points out, these categories should rather be seen as a scale since there is no such thing as a perfectly structured or unstructured interview. The design of the interview study for this project is based on the definition of a semi-structured interview, which is closely linked to the qualitative research approach (Brinkmann, 2013). An interview guide (see appendix I) was developed and used for the interviews, which provided an outline for the interviews but still allowed the interviewees to respond with their own words, for discussion and for follow-up questions .

The semi-structured interview form allowed for discovery of unpredicted answers and the exploration of unknown aspects of the research subject, but at the same time the structured focus facilitates the analysis (Gillham, 2005). An advantage of the semi-structured interview form is that it makes it possible to follow up on interesting answers and fully exploit the knowledge-creating potential of a dialogue (Brinkmann 2013).

According to Gillham (2005), an expert interview is a means of gaining access that is not necessarily accessible in written form. In some cases, the experts may not be ready to commit themselves on paper, but are comfortable airing their ideas and experiences in an open interview. In other cases the expert may not have bothered putting the knowledge on paper or it may be too recent. The simple method of asking someone who is knowledgeable on the chosen research subject is still a viable method of gaining knowledge and is not out-of-date despite the sophisticated search engines that exist today. Human intelligence has the advantage that it can make associations and draw conclusions and is not dependent on a specific key word like a database information search. (Gillham, 2005)

The definition of an expert interview is based on the definition of an "expert". For the purpose of this report, an expert is someone who is assumed by the researcher to have *"knowledge, which she or he may not necessarily possess alone, but which is not accessible to anybody in the field of action under study"* (Meuser & Nagel in Bogner, Littig & Menz, 2009, p. 18). When interviewing experts, the interviewer needs to be aware of his or her prejudices and not expect certain outcomes. It is also important to keep in the wording of the questions, otherwise the interviewer risks finding themselves reprimanded by the interviewee who might not be of the same opinion (Gillham, 2005). This was taken into account when doing the interviews for this thesis, considering the researcher's previous experience of energy performance regulations and the market introduction of innovations. Attention was made to make the wording of the questions neutral and avoid asking leading questions.

One of the biggest challenges with qualitative interviewing is not the interview in itself but the work afterwards with compressing the large number of pages of transcripts into a relevant analysis (Brinkmann, 2013). Since the interviews for this thesis were conducted in French and Swedish, the interview results that are presented in this report have been translated to English by the researcher. As a part of interview courtesy the interviewees were informed in the "consent" stage that they will have the possibility to read the transcript. According to Gillham (2005) the offer is usually declined but it can be an important condition, especially in élite interviews, to get an interview. The interviewees were given the possibility of reading both the transcript of their interview in its original language as well as the results of the interview in English before publication.

Six semi-structured expert interviews were performed. Some of the interviews were face-to-face whereas others were done over the phone. The main reason for choosing to perform distance interviews instead of interviewing face-to-face was the lower costs, or that it was the only possibility of performing the interview (Gillham, 2005). In this case, the telephone interview made it possible to interview persons who were located in different countries and cities. The interviews lasted between 30 and 60 minutes.

Different actors were interviewed in France and Sweden, respectively, and were considered to be experts. The interviewees were considered to possess exclusive knowledge and be able to draw conclusions on the impact of the EP regulation in their country thanks to their professional situation. These interviewees have different knowledge and experience on the subject of EP regulations and the expected impact on innovation. This is why the questions asked differed between the actors in a country, but the same questions were asked to the actors in the two countries in their respective languages. The consultant in France was asked different questions than the authority representative in France, but the same questions as the consultant in Sweden. The original interview guide (which can be found in appendix I) was done in English, whereas the interviews were performed in either French or Swedish.

The following actors were selected to participate in the interview study:

Actor 1: Actor working for the authorities. This actor participated in the elaboration of the EP regulation and is considered to be well implicated with the regulation from a policymaker point of view. This actor contributed with information about why the regulation is designed the way it is, and what the intentions from the lawmakers' side were.

Actor 2: Representative for industrial association. In both France and Sweden there are industrial associations regrouping companies within the HVAC industry and representing their interests. The French organization represents practically the whole HVAC sector, whereas the Swedish organization in the study only represents the ventilation sector. Instead of interviewing representatives for a particular company, the intention of interviewing a representative from an industrial association is to get a more general picture of what the industry thinks.

Actor 3: Consultant working with the energy performance of buildings. This actor represents the engineers that apply the EP regulation on real projects and needs to be comfortable with it. The consultants that participated in the study were selected because of their large experience and were expected to be more knowledgeable on the subject of EP regulations than the average consultant. Due to the differences between the EP regulations, the expected experiences of the consultants differed. For example, the French consultant was expected to be knowledgeable about the application of the regulatory calculation method, whereas the Swedish consultant was expected to know about measuring energy use of a finished building.

Due to differences between the countries the actors are not perfectly analogous, but were considered to have similar functions and experiences for the purpose of this thesis. The selection of different actors with different points of view also represents a type of triangulation. Not between methods but within a method, permitting to discover different points of view of the same phenomena and thereby increasing the validity of the results (Svenning, 2000).

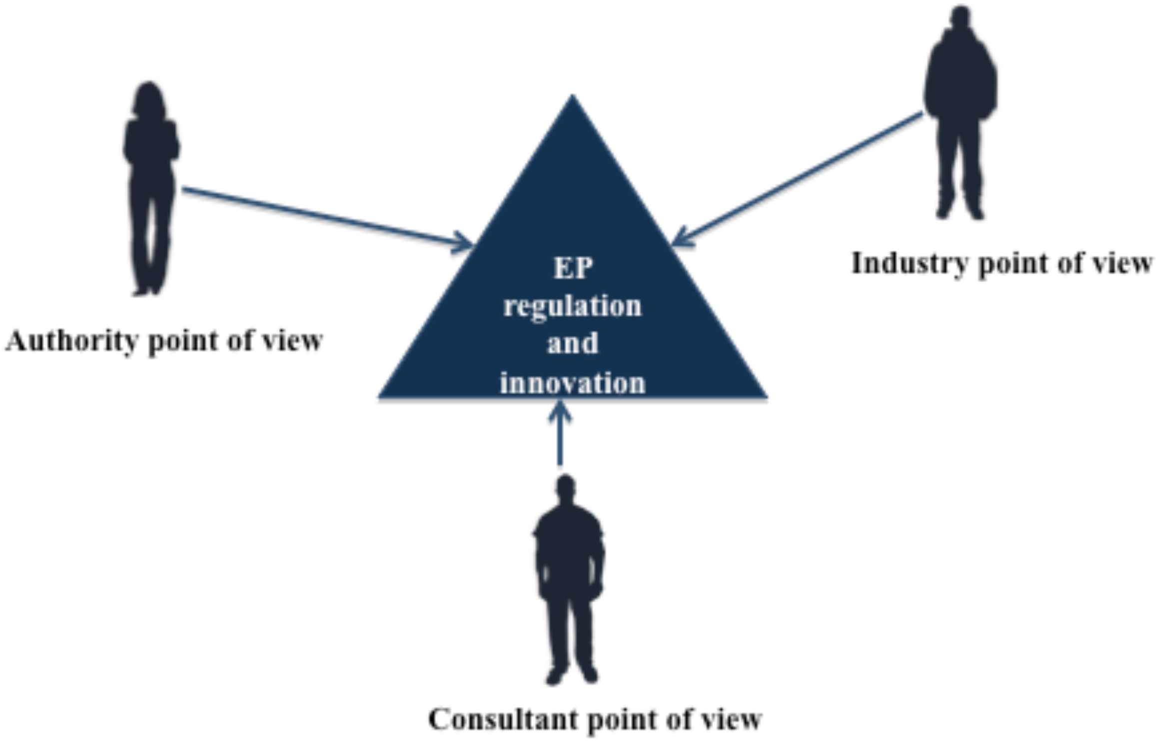

Figure 2. Triangulation within a method; interviewees

The interviews were recorded and later transcribed by the researcher. The interviewees gave consent to audio recording of the interviews. The interviews were transcribed in their original language, and then translated to English when inserted in the report.

The interviewees were asked different questions relevant for their respective expertise. The transcripts were read through several times in order to be able to sort and label the answers in a structured way with both similarities and differences visible. The labels also made it possible to get an overview of the material as well as identifying information gaps in the data. Additional supplements to some of the interviews were made via e-mail. The result of the interviews is presented in chapter 4 where the sorted different labels serve as headings.

2.4.4. Analysis of data from the desk study and interviews

As previously mentioned, the data from the desk study and the interviews were joined in the analysis. There are many approaches that can be used to analyze data. The phases defined in Rapley (2011, p. 274) provided a guideline for how the analysis should be performed, moving from a detailed to a more abstract level where the data is labeled and a comparison between the results from France and Sweden could be made. As previously mentioned, occasionally some of the phases were in progress at the same time.

1. *Development of theoretical framework.* The theoretical framework emerged while working with the literature review. The elaboration of the theoretical framework guided the data collection in terms of questions asked in the interviews and information included in the desk study.
2. *Familiarization with the dataset.* The researcher was already familiar with a large part of the data for the desk study due to the previous work experience. For the interviews,

the process of transcribing them allowed the researcher to become more familiar with the content.

3. *Indexing; sorting and labeling of data.* The data from the interviews and the desk study was assessed and labeled in a way that related to the characteristics defined in the analysis model.
4. *Application of analysis model.* The results of the interview and desk study were analyzed using the five regulation design characteristics, stringency, flexibility, certainty, transparency and enforcement in the analysis model. The results were then compared in order to see how they relate to each other and if they concur or not.

3. Theory

Concepts necessary in order to understand the context of this thesis are presented first in section 3.1. In section 3.2, the results of EU-financed projects provide a background to previous findings specifically related to EP regulations and innovation. The studies that formed the theoretical framework for this thesis are presented in sections 3.3-3.5. More specifically, a review of studies covering the relationship between regulations in general and innovation are presented in 3.3. The results of studies discussing the impact of regulation design on innovation are presented in section 3.4. The proposed analysis model and definitions of the included regulation characteristics considered to have an impact on innovation are presented in section 3.5.

3.1. Central concepts

3.1.1. Energy Performance of Buildings Directive (EPBD)

As mentioned in the introduction, the EPBD came out in 2002 with the main objective of reducing the energy consumption of the buildings in the EU. A recast of the EPBD came out in 2010. As a directive, the EPBD sets out objectives that are to be reached by the member states, but leaves it up to the member states to decide how this is to be done. The member states must adapt their laws and regulations in order to attain the objectives of the directive within a given time (European Law Monitor, n.d.). The requirements of the EPBD on the member states include setting quantitative minimum requirements for the energy performance of buildings and building elements. The EPBD further specifies that the energy performance of a building is to be calculated using a methodology that is based on European standards. The calculation methodology should take into account thermal characteristics of the building as well as HVAC installations, design of the building, energy from renewable sources, passive heating and cooling, indoor climate and shading (European Commission, 2010).

In terms of future requirements, the EPBD declares that member states are to ensure that by 2020 all new buildings are nearly zero-energy buildings. A nearly zero-energy building (nZEB) is defined as *"a building that has very high energy performance [...]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources"* (p. 18). It is the responsibility of the member states to apply the EPBD and set the quantitative requirements for a nZEB in their country, depending on local conditions (European Commission, 2010).

3.1.2. Energy Performance (EP)

A central concept of this thesis is energy performance of buildings. In the EPBD recast it is defined as *"the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, inter alia, energy used for heating, cooling, ventilation, hot water and lighting"* (European Commission, 2010, p.18). The term energy performance is often used interchangeably with energy efficiency in literature on the subject, and is even translated as energy efficiency in for example the Spanish version of the EPBD according to Casals (2006). Both energy performance and energy efficiency have the same objective but since energy efficiency is dimensionless it is not a suitable indicator to use in a building regulation. The energy performance of a building should be expressed using a quantitative indicator such as kWh/m^2.year. This makes it possible to assess the impact of choices in building design and systems on its energy consumption and compare them (ibid.).

3.1.3. Regulation

According to Kemp, Smith and Becher (2000) there is no common definition of regulation, but most definitions involve government control over firms' activity in order to favor the interests of the public. In their report they refer to regulation as *"command-and-control measures to control market imperfections"* (ibid., p. 9) According to the Merriam-Webster Dictionary, a regulation is *"an official law or rule that says how something should be done"* (Regulation, 2015). Allen and Sriram (2000) define regulations as a subcategory of standards, and state that *"regulatory standards ensure conformity in processes that are not driven by market forces"*. Foliente, Leicester and Pham (1998) define building codes or regulations as *"a document used by a local, state or national government body to control building practice, through a set of "acceptable" minimum requirements of building performance"* (p. 22)

When it comes to environmental regulation, it is one of many different environmental policy instruments used to reduce pollution and emissions for example. Other policies include taxes, subsidies and information (Johnstone et al., 2010). Environmental policy is often categorized into three categories: direct regulation (command-and control), economic instruments and soft instruments (Annunziata, Rizzi & Frey, 2012). Regulations are also supposed to level the playing field for companies, so that no company can avoid the costs involved with environmental improvements and create an "artificial" demand for new technologies (Porter & van der Linde, 1995; Dewick & Miozzo, 2002)

3.1.4. Energy Performance regulation

Gann, Wang and Hawkins (1998) stated that the "energy performance" approach in a building regulation implies specifying a final goal but not how it is to be reached. This approach allows for trade-offs between different building parts, where the use of energy efficient appliances can compensate for less insulation for example (Noailly, 2012). The performance approach is relatively new, and has become increasingly popular in building regulations since the 1980's (Perez-Lombard et al., 2011). Traditionally, building regulations set prescriptive requirements (such as for example U-values of the building envelope or efficiency of heat exchangers) on independent building elements assuring easy compliance and enforcement. These low-level requirements were considered to result in cost-effective energy savings, but the prescriptive approach was criticized for limiting designer freedom and inhibiting innovation by prescribing certain solutions instead of defining overall targets (Perez-Lombard et al., 2011). Building regulations with requirements on energy performance have proven to be successful in improving the energy efficiency of new buildings (ibid.) and according to the IEA (International Energy Agency) the energy performance of buildings in many countries has improved as the building energy regulations are strengthened (Laustsen, 2008).

Early building energy regulations focused mainly on improving the building envelope (Laustsen, 2008; Pérez-Lombard et al., 2011) but since heating, ventilation and air-conditioning represent half of the energy use of buildings in developed countries today (Pérez-Lombard, Ortiz & Pout, 2008) Pérez-Lombard et al. (2011) consider HVAC energy efficiency requirements to be key in order for a regulation to succeed in increasing the energy efficiency of buildings.

Meacham (2010) specifies facilitation of innovation in the building sector as a contributing reason for countries to adopt a performance approach in their building regulations. Naturally, shifting from a prescriptive to a performance approach does not solve all problems Meacham (2010) and Pérez-Lombard et al., (2011) present two main challenges associated with the performance approach: developing an assessment method for the energy performance of buildings and defining the global energy performance requirement. In order for performance based building codes to be successful in reaching the global goal it is necessary that they are based on clear objective performance criteria and assessment methods (Foliente et al., 1998).

Since the EPBD leaves it up to the member states to define the calculation methodology and set the performance requirements there are large differences between the energy performance regulations in the Member States, both in terms of general approach but also how they integrate innovations (Spiekman et al., 2010). The EPBD requires that the minimum EP requirement levels are reviewed and if so needed, revised in order to *"reflect the technical progress in the building sector"* (European Commission, 2010, p. 19).

3.1.5. Innovation

According to Beerepoot (2007) innovation has historically been the interest of economic research theory but has grown into a multidisciplinary field of research with its own (somewhat undefined) theoretical framework. Garcia and Calantone (2002) concluded that innovation has been defined in many different ways, for different purposes and it is not always evident how to differentiate between the different definitions. In reviewing literature they found an OECD definition from 1991 to be the most relevant general definition of innovation: *"'Innovation' is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production and marketing tasks striving for the commercial success of the invention"*.

In this definition, it is important to note the difference between 'invention' and 'innovation'. An invention is the development of a new idea (Ashford et al., 1985) and it is not considered an innovation until it is available to the market, after being produced and marketed (Garcia & Calantone, 2002). Ashford et al. (1985) define technological innovation as "*the first commercially successful application of a technical idea*" (p. 419). Pelkmans and Renda (2014) provide a definition of innovation where a new product is considered to be an innovation based on whether it can provide a long-term contribution to society in a resource efficient way.

3.2. Previous findings on the impact of EP regulations on innovation

When it comes to the effect of regulations stemming from the EPBD on innovation, Beerepoot (2007) found that virtually no research had been performed and Pelkmans and

Renda (2014) discussed the lack of evaluation of the impact of EU regulations in general on innovation. The difficulties in finding scientific articles on the subject for this thesis suggest that not much research has been done on the impact of EP regulations on innovation since 2007. The impact of EP regulations on innovation has been studied within the scope of some EU-financed projects. An objective of these projects was to explore if there was a way of assessing innovations within the framework of EP regulations and to find a procedure that ensures the quality of the performance assessment without being overly complex, expensive or time-consuming (Spiekman et al., 2010). In these studies, it is supposed that there is a regulatory calculation method and the impact on innovation is assessed within that context. The current Swedish approach with measuring energy use of the finished building and not defining a regulatory calculation method was not evaluated. The results of these projects are therefore not applicable for a comparison between France and Sweden but parts of the work done within the EU projects were still considered relevant for this thesis and are presented below. For this thesis, the results of the following projects were reviewed:

- ENPER-TEBUC (2001-2003). Within the scope of this project, the possibilities of harmonization of the European building codes and best practice approaches for Energy Performance of Building regulations were explored as well as the subject of EPB regulations and innovation. The ENPER (Energy PERformance of buildings) part of the project was mainly concerned with the assessment of the energy performance of buildings and determining best practice principles to be included in new harmonized regulations. Innovative systems and technologies were considered as necessary in order to improve the energy efficiency of buildings. TEBUC is an abbreviation for “Towards a European Building Code” and the treatment of innovative systems is considered as a key point in progressing towards harmonization of the European energy building codes (Dicke, Weber, Kjellsson, & Despretz, 2003).
- Reshyvent (2002-2004). A part of the project, whose main focus was demand controlled hybrid ventilation in dwellings, was proposing a method for assessing the performance of innovative ventilation systems within the framework of EPB regulations (Wouters, Heijmans & Loncour, 2004).
- ASIEPI (2007-2010). ASIEPI stands for “Assessment and Improvement of the EPBD Impact” and one of the topics studied was “The EPBD as support for market uptake for innovative systems”. An objective was to explore if there was a way of assessing innovations within the framework of EPB regulations and to find a procedure that ensures the quality of the performance assessment without being overly complex, expensive or time-consuming (Heijmans & Spiekman, 2010).

In the final report for the ASIEPI project that was published in 2010 it is stated that “*The EPBD is one of the European Union's tools to reduce its energy consumption. New and innovative products, systems and technologies may help to achieve this final goal. It is therefore of vital importance that EPBD related regulations don't become barriers to innovation”* (Heijmans & Spiekman, 2010, p. 6). The topic of the EPBD serving as an incentive for innovation is given such importance by the authors that an obligation of defining a method for assessing the performance of innovative systems not covered by the standard calculation method in future versions of the EPBD is proposed (Heijmans & Spiekman, 2010).

Within the scope of these EU projects, innovation is defined as *"systems (or technologies) that in most cases give a better performance in term of the energy performance of buildings than the common technologies and whose performance cannot be assessed by the standard EPB calculation in a particular country"* (Heijmans, Wouters, & Loncour, 2008, p. 1355*)*. The innovativeness is thus based on whether the performance of the innovation can be assessed using the regulatory calculation method of a particular country or not, and implies that a system or technology can be regarded as an innovation in one Member State but not in another (ibid.). The impact of EP regulations on innovation was considered increasingly relevant, since the industry looks at the EP regulations to a larger extent in relation to product development. According to the Reshyvent project, one of the key questions for the industry was "*how can we improve and optimize our products with respect to the performance assessment made in EP regulations?"* (Wouters et al., 2004, p. 17). From the point of view of the innovating companies, the stricter and heavier the framework, the stronger the perceived barrier to innovations. A heavy framework means more time and effort needs to be spent in order to prove the performance of the innovation, whereas it is automatically integrated in an open method regulation. According to Spiekman et al. (2010) this perception does not completely reflect reality because open calculation methods and light regulatory frameworks can be barriers to innovation as well if the real performance of the innovation does not live up to the claimed performance. If false performance claims are accepted in the EP calculation method, the regulation in itself becomes weakened since the calculated EP values will be erroneous. For the firms this can affect their credibility, if it turns out their products do not have the claimed energy performances (ibid.).

Within the Reshyvent project, Wouters et al. (2004) found that regulations could have a strong impact on the market. This was illustrated by the example of humidity-controlled ventilation in France. This technology is included in the standard regulatory calculation method in France, resulting in millions of devices being sold in France whereas the market outside France is rather limited since there is no regulatory incentive. In the TEBUC project it was found that regulations can decrease firms' perceived uncertainty on future savings achieved by an innovation by making it a societal norm. An example of this is the German Waermeschutzverordnung from 1995 that had a positive impact on the introduction of energy-efficient windows in Germany and led to a decrease in costs. (Dicke et al., 2003)

On the other hand, Wouters et al. (2004) claim that an energy performance regulation can impose an important market barrier to innovations that fall outside the standard regulatory calculation procedure. The idea of an energy performance regulation is to make it possible to compare the improvement in energy efficiency versus the investment cost for different technologies and let the market choose the best alternative. If the energy performance of the innovative system or technology cannot be calculated using the standard calculation procedure their potential advantage in terms of energy performance cannot be proven and they fall out of the market. (ibid.)

Since accounting for all innovations in a regulatory calculation method is impossible, Dicke et al. (2003) suggest that an alternative assessment procedure for innovative systems and concepts needs to be developed. The solution proposed in the EU projects is an alternative calculation method for innovations, referred to as "Principle of Equivalence". The "Principle of Equivalence" was considered necessary as "escape route" in order to *"allow the not covered technologies to enter the competition by allowing the official calculation of their impact on the energy consumption of the buildings"*. (Wouters et al., 2004, p. 12) In order for the reliability of the regulation to be preserved it is important that the scientific principles behind the alternative assessment method are clearly defined (ibid.).

Within the ASIEPI project, several specific challenges related to the "Principle of equivalence" were identified. The first was finding a way to deal with the complexity of the assessment of the performance of an innovative system as combined with a need for quality and reliability. Suggestions for dealing with these issues within the framework of a "Principle of equivalence" include handling time delay and costs for equivalence studies. Transparency, in terms of keeping the industry informed about the requirements and opportunities with the alternative assessment method is also discussed. (Heijmans & Spiekman, 2010) In the TEBUC project it was recommended that the procedure includes expert consultations since it implies more flexibility than trying to define an assessment method applicable for every imaginable innovation in advance. (Dicke et al., 2003) Important factors in order for the alternative assessment method to fulfill its purpose include well-defined boundary conditions and transparency towards the industry on a European level. (van Dijk & Spiekman, 2004). A stepwise increase of the regulatory stringency was recommended and believed to serve as an incentive to innovate beyond the energy performance requirements already in place (Dicke et al., 2003).

According to the Reshyvent project, it is of outmost importance that there is transparency in relation to the assessment method. The opinion of the participants in the Reshyvent project and European manufacturers that participated in the project this transparency was found to be lacking for many innovative systems (Wouters et al., 2004). Spiekman et al. (2010) emphasize the importance of understanding the technical complexity of modern buildings and innovational systems. Demonstrating that an innovation improves the energy performance of buildings is therefore an intricate task. According to Spiekman et al. (2010) the calculation of the EP of a building is not an exact science, and it is very difficult to predict the true energy consumption of the finished building. Indoor and outdoor climate, number of occupants and user behavior are all factors that are difficult to define but that have an important impact on the final result of the calculation. Therefore, an EP calculation is not a strictly scientific task and it also involves making arbitrary choices that can favor different interest groups. As always, when the choices are arbitrary, they can be debated even when supposedly independent experts are involved. EP regulations risk becoming subject to lobbyist efforts, where strong market forces try to influence the decision makers in a way that will favor their sector by including certain elements or requirements in the regulation (Spiekman et al., 2010). A stepwise increase of the regulatory stringency found by Dicke et al. (2003) to serve as an incentive to innovate beyond the energy performance requirements already in place.

3.3. Impact of regulation on innovation from a general perspective

Neither governments nor innovative firms can predict the direction of technological change, and it is therefore important that the regulation does not block the way for innovation that can lead to new solutions that are better for the environment than the existing ones (Johnstone et al., 2010). According to Beerepoot (2007) previous studies have concluded that government regulation should play a role in promoting innovation, but cites multiple authors claiming that just setting a requirement cannot be expected to result in innovation since it does not provide the companies with an incentive to do better than the regulation requires. In order to create an environment that is conducive to innovation, Ashford et al. (1985) state that it is important that the regulator analyzes the innovative dynamic of the sector, and not what is possible with current technology. This analysis is also important in order to avoid that the regulation promotes idiosyncratic innovations according to Beise and Rennings (2005). Dewick and Miozzo (2002) have identified what they refer to as an "innovation-regulation paradox", stating that *"the former is concerned with re-writing the rules and replacing the incumbent products and processes specified by the latter"* (p. 824). Despite this paradox, they conclude that both regulation and innovation are necessary in order for the construction industry to become more sustainable. Allen and Sriram (2000) define regulations as a category of standards, and state that standards can both hinder innovation, by cementing and giving advantage to existing technologies, and drive innovation by increasing global competitiveness. They also claim that standards provide a favorable environment for innovation by setting requirements on performance, conformity and safety of new products. According to Heijmans et al. (2008) building regulations can be a catalyst to the market uptake of energy-efficient innovations but also risk becoming a barrier if the assessment of the performance of innovations is not possible within the framework of the regulation (ibid.)

Traditional economist theory regards regulation and technological innovation as mutually incompatible, according to Gann et al. (1998), believing that standards restrict freedom and hinder innovation. It is supposed that protecting the interests of the public and the environment with environmental regulation will inevitably lead to increased costs for firms potentially reducing their industrial competitiveness (Porter & van der Linde, 1995). This is why firms instinctively turn against increased environmental regulations and increased stringency since the adaption to new regulations inflicts a cost while not guaranteeing future savings (Dewick & Miozzo, 2002). In their article from 1995 Porter and van der Linde challenge the traditional economist view on the relationship between environmental regulation and innovation where regulation inevitably deters innovation. Porter and van der Linde claim that *"properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs for complying with them"* (p. 98). This is often referred to as the Porter hypothesis. The authors believe that regulation can have an impact on innovation in many different ways. Regulations can help increase companies' awareness of certain environmental issues, reduce uncertainty thus making companies more willing to invest in innovative activities and put pressure on companies making them feel obliged to progress (Porter & van der Linde, 1995). This idea concurs with the findings of

Ashford et al. (1985), who present the idea that it can be more costly to comply with existing regulatory requirements using a new technology, but that the new technology makes it possible to comply with stricter regulations to a lower cost. A regulation designed for promoting innovation should therefore be based on the concept of technological change.

Beerepoot (2007) proposes using an innovation systems approach for studying the relationship between innovation and regulation. This approach defines innovation as part of a larger context, which involves analyzing the complex links between organizations, institutions and the industry. Innovation is regarded as a product of complex interaction between the innovating firm and its environment, which is referred to as the "innovation systems approach". The impact of regulation on innovation is not as simple as either hindering or encouraging, and regulation is rather *"a 'modulator' of technical change, changing directions and modes of innovation rather than just stopping or starting it"* (Kemp et al., 2000, p. iv). Innovation is not an isolated phenomenon within a firm, but is affected by a multitude of framework conditions of which some are illustrated below. These conditions are dynamic and often specific for a region or country (Kemp et al., 2000).

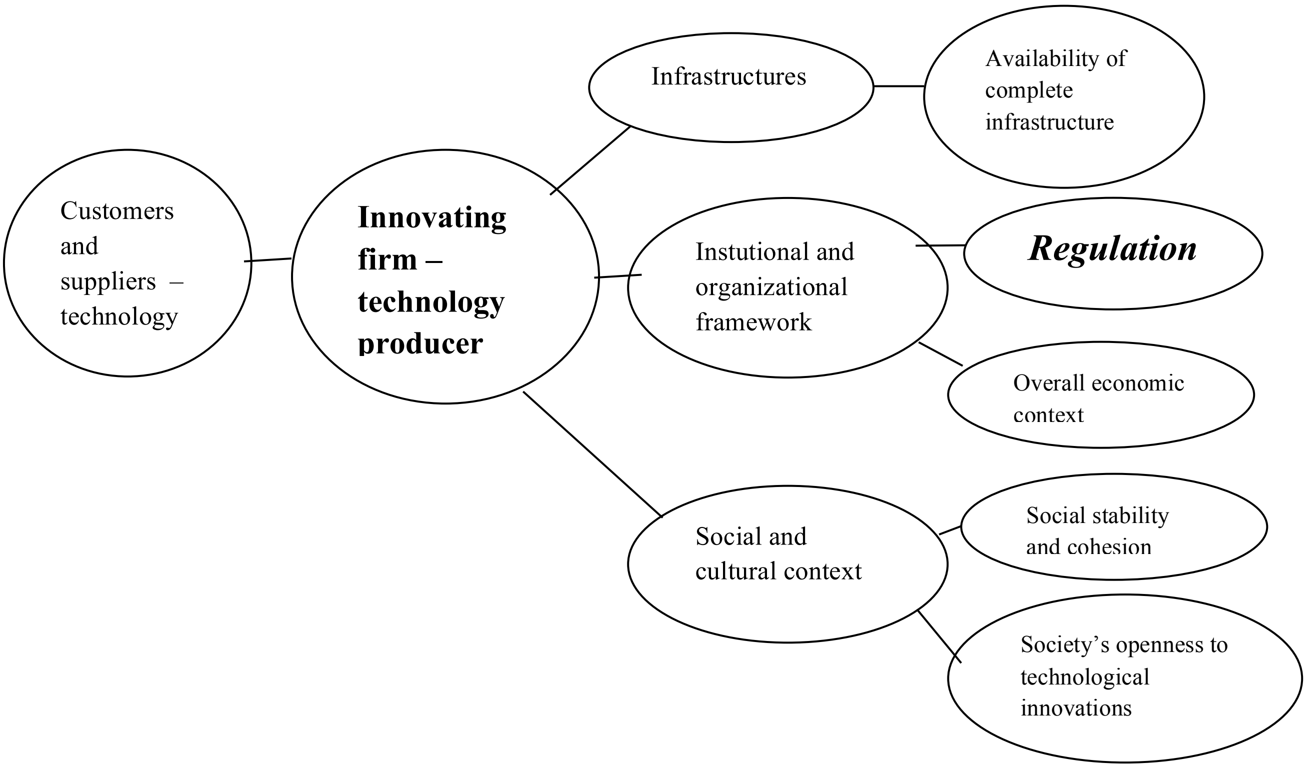

Figure 3. An innovation system, based on the reasoning in Kemp et al. (2000).

According to Johnstone et al. (2010) there is empiric evidence that marked-based instruments are more likely to induce innovation than direct regulations, but claim that the characteristics of the policy instrument is more important than the broad policy type. This is confirmed by Bergek and Berggren (2014) who found that both regulatory and economic policy instruments can have a positive impact on emissions and innovation, and that design characteristics play an important role in the success of a policy. Kemp and Pontoglio (2011) came to a similar conclusion stating that *"the impacts of environmental policy instruments on innovation may depend more on design features than on the type of instrument chosen"* (p. 34).

3.4. Impact of regulation design on innovation

In order to have a driving effect on innovation, regulations should be elaborated following three steps according to Porter and van der Linde (1995): The first step involves creating leeway for firms to innovate, by setting result requirements and leaving it up to the firms to find solutions to live up to them. The second step involves focusing on outcomes and not being partial towards a specific technology. Thereby continuous technological evolution is encouraged. The third step involves reducing the risk of uncertainty and making sure the regulation is clear, coherent and accepted by the industry. The firms can then focus on innovating in line with the regulation instead of fighting to change it. Porter and van der Linde (1995) claim that regulatory stringency has an impact on firms' willingness to innovate, since lax regulatory requirements can often be handled without innovation. According to Pelkmans and Renda (2014), stringency is a *"double-edged sword"*, where too high stringency levels can lead to firms who cannot live up to the requirements go out of business and there is a discouraging effect on the innovative ambitions of other firms.

Beerepoot and Beerepoot (2007) studied the impact of gradually stricter building energy regulation on innovation in the Dutch building sector using an innovations systems approach. Data from 350 energy performance of buildings calculations that had been submitted to Dutch authorities between 1996 and 2003 was used for the study. The authors found that between the years 1996 and 2003, the Dutch energy performance regulation had not been stringent enough to promote the development of really new innovation. The evolution during this period consisted of improvement of already existing technologies. The findings of Beerepoot and Beerepoot (2007) confirm previous research claiming that non-stringent regulations mainly lead to an amelioration of existing products and no really new innovations.

Stringency was one of the policy characteristics whose impact on innovation was studied by Johnstone et al. (2010). They used a worldwide database of patent applications to study the effect of environmental policy stringency, predictability and flexibility on innovation. They found that increased policy stringency led to more innovation in the field of emission reduction. Policy uncertainty resulted in less environmental technology innovation whereas policy stability and predictability made innovation more likely. For a given stringency, the authors found that a more flexible and technology-neutral policy increased the probability of innovation taking place.

Rothwell (1992) studied the impact of environmental regulation on innovation during the latter part of the 20th century and found that environmental regulation is not necessarily a barrier to innovation but can be if not properly designed. Standards that were too general, unrealistic and not clearly based on scientific evidence were found to have a negative effect on innovation. Long waiting times for regulatory approval can cause delays in the market launch of new products. According to Rothwell (1992), high regulatory compliance costs can lead to research and development (R&D) resources being focused on regulatory compliance instead of commercially oriented innovation. Elevated costs and delays related to regulation were found to have an especially large negative impact on small entrepreneurial innovative companies. Uncertainties over future regulation along with inconsistent or unclear regulations may reduce manufacturers' willingness to take the risk and invest in innovation projects. In order to increase the chance of innovation taking place performance based standards are preferred over specification standards due to the formers' intrinsic flexibility.

Meacham (2010) found that performance based building regulations allow for more flexibility than prescriptive regulations, but noted that there are important challenges related to the performance approach. These include how to assure that the innovation works as claimed when installed in a building, correct use of computer calculation software and how to administer oversight and controls. Another difficulty is the tradeoff between controls and flexibility. Strict controls imply consistency and accountability, but possibly at the price of flexibility and innovation. Meacham (2010) emphasized the importance of a functioning procedure for evaluation of the performance of an innovation and increased verification and validation of results from computational tools.

Gann et al. (1998) investigated the impact of building regulations on innovation, and focused on the differences between performance based regulations and prescriptive regulations in providing a favorable environment for innovations. According to the authors, stringent standards can create a market demand for high performance technologies that would not be successful otherwise and thereby reduces the risk for the innovating company. Through interviews with manufacturers they found that stricter regulatory requirements incited manufacturers to ameliorate their products. The necessity for regulatory clarity and simplicity in the regulatory process was brought up by Gann et al. (1998) as a factor impacting innovation, along with stringency and flexibility (ibid.).

According to Ashford et al. (1985), strict enforcement of a regulation can have an impact on the innovation ambition in a sector. Besides enforcement, the time for compliance was found to have an impact on innovation, since innovating firms anticipate and try to comply with future regulations. Uncertainty was found to have a double impact on innovation: too much regulatory uncertainty can have a negative influence on the industry's readiness to innovate, since it implies that the innovation might not be demanded by the market or not be cost efficient. Too much certainty will only result in innovations that fulfill the requirements but not more. Ashford et al. (1985) considered stringency to be the most important regulatory factor for technological innovation.

In a study on the impact of environmental policy on innovation, Noailly (2012) also found stringency to have an impact on innovation. Regulatory energy standards in building codes were one of the three policy types investigated in a study on how energy efficient innovations in the building sector were affected by environmental policy. Using patent counts, Noailly (2012) found that compared to the impact of energy prices and governmental R&D expenditures, strengthening the regulatory standards would have the most important impact on innovation. Enforcement of the regulation was also considered to affect the number of patents. In countries where enforcement of the building code through monitoring and controls was considered to be weak, the regulation was found to have no clear impact on the number of patents (ibid.).

The results of Noailly (2012) were cited in Bergek and Berggren (2014) for the purpose of a study on the effect of environmental policy instruments on innovation. Bergek and Berggren found that environmental policy instruments face challenges such as selection, stringency, stability and scale. Selection relates to technology neutrality, and the authors conclude that also general policy instruments lead to a certain advantageous selection of for example mature technologies before less developed. A part of this can be avoided by taking all available information on performance and cost comparisons of different technologies into account when developing the policy. Stringency is found to be an important issue for all the policy instruments in the study and a stepwise increase of the policy stringency is considered necessary to avoid a decline in innovative efforts. Perceived stability and predictability of a policy instrument are given significance, and according to the authors EU regulations have more stability than national regulations, since they are set on a higher institutional level.

Noailly and Batrakova (2010) studied the connection between technological innovation and public policies in the building sector over the last 30 years. Empirical evidence was collected using patent data from national offices in several European countries in the field of building energy efficiency. Policy design, in terms of flexibility, stability and continuity were found to be important for innovation. A frequently changing policy framework may lead to firms postponing irreversible R&D investments and consequently a decrease in innovation.

Türpitz (2003) studied eco-friendly product innovation activities in companies via several case studies of industrial companies in Germany. The expert interviewees identified many difficulties involved with eco-innovation, mainly concerning the commercialization of environmentally friendly products. Risks included high investment costs and uncertain profitability. According to the author these difficulties contribute to making regulation one of the most important drivers for ecological product innovation. Surveyed companies looked to comply with existing regulations as well as anticipating future regulations. According to Türpitz (2003) the impact of anticipated regulations has a driving effect on companies' innovative behavior since they make the companies aware of issues that need to be attended to.

In an extensive literature study Kemp and Pontoglio (2011) reviewed the impact of environmental policy instruments on innovation. They discussed the difficulties associated with measuring environmental policy, the measuring of innovation and other influential factors that cannot be observed such as business expectations. The authors defined the following policy elements as being significant to innovation: stringency, predictability, timing (moment when the policy comes into effect, use of phase-in periods), credibility of policy commitments to future standards, possibilities for monitoring compliance and discovering non-compliance, enforcement (inspections and penalties for non-compliance).

3.5. Regulation design characteristics impacting on innovation and proposed analysis model

In reviewing previous research within the theoretical framework for this thesis concerning the impact of regulation on innovation, specific regulation design characteristics considered to have an impact on innovation were identified. These five characteristics form the analysis model that is used to analyze the results from the desk study and the interviews. The five characteristics that were found to be the most relevant to the case of EP regulations and their effect on innovation are stringency, certainty, flexibility, transparency and enforcement. They were selected based on if their relevance was confirmed in multiple studies, if they were definable and if they could be considered applicable to the case of EP regulations and HVAC innovation.

Table 1. Analysis model

Characteristic:	Impact on innovation discussed in:
Stringency	Porter and van der Linde (1995), Noailly (2012), Gann et al. (1998), Beerepoot M. and N. (2007), Ashford, Ayers and Stone(1985), Bergek and Berggren (2014), Johnstone, Hascic and Kalamova (2010), Kemp and Pontoglio (2011)
Certainty	Porter and van der Linde (1995), Ashford, Ayers and Stone(1985), Bergek and Berggren (2014), Johnstone, Hascic and Kalamova (2010), Noailly and Batrakova (2010), Rothwell (1992), Türpitz (2003), Kemp and Pontoglio (2011)
Flexibility	Porter and van der Linde (1995), Gann,Wann and Hawkins. (1998), Johnstone, Hascic and Kalamova(2010), Rothwell (1992), Meacham (2010)
Transparency	Rothwell (1992), Porter and van der Linde (1995), Gann, Wann and Hawkins, (1998)
Compliance/Enforcement	Noailly (2012), Ashford, Ayers and Stone (1985), Meacham (2010), Kemp and Pontoglio (2011)

Other regulation design characteristics that were highlighted but not included in the theoretical framework are international harmonization (Rothwell, 1992), targeting (Noailly & Batrakova, 2010), combination with other policies in place (Kemp & Pontoglio, 2011), time for compliance (Ashford et al., 1985) and depth (Johnstone et al., 2010) These characteristics are not included in the theoretical framework either because the reviewed studies did not provide enough support to their relevance to innovation or because no definition of what the authors meant with the characteristic could be identified.

The meaning and definition of the five characteristics included the analysis model are presented in the sections below.

3.5.1. Stringency

Regulatory stringency has been found to be a relevant aspect to innovation in many studies, though the term was rarely explicitly defined in the reviewed literature. Johnstone et al. (2010) summarizes stringency as *"how ambitious is the environmental policy target, relative to the "baseline" trajectory of emissions?"* (p. 6). Ashford et al. (1985) consider that a regulation is stringent if it requires significant reductions, makes using existing technology costly or makes technological change necessary in order to comply. They further conclude that that the stringency of a regulation can be assessed both based on the extent to which it reduces risks (for the purpose of this thesis: the extent to which it reduces buildings' energy consumption) and how well it drives innovation.

In this thesis, stringency will refer to the quantitative energy performance requirement in the EP regulation. This is a simplification of the complex concept of regulatory stringency and difficulties relating to how it should be assessed. According to Brunel and Levinson (2013) the complexities related to regulatory stringency include the differences between countries in terms of progress in environmental issues, the multidimensionality of what media is to be regulated as well as how and what to measure. A direct comparison between the stringency levels in France and Sweden is not relevant for the purpose of this thesis, since the EP requirements are not based on the same values in France and Sweden (calculated and measured, respectively), and also due to the differences in climate as well as the different building traditions in the two countries.

3.5.2. Certainty

Regulatory certainty is related to predictability and if the message that the policy-setting agency sends to the industry is consistent and reliable (Johnstone et al., 2010). A message that is uncertain in terms of the direction of future regulatory requirements may be a brake to innovation (Ashford et al., 1985).

3.5.3. Flexibility

According to Johnstone et al. (2010) flexibility implies letting the companies find the best way to meet the objective and not pre-defining solutions. Flexibility relates to whether the policy provides multiple ways of compliance or only one (Johnstone et al., 2010). Regulatory flexibility is associated with the performance-based approach (Gann et al., 1998; Rothwell, 1992), which implies leaving the door open to innovative solutions as long as they acquire the final objective. Another aspect of flexibility is avoiding locking into a specific technology (Porter & van der Linde, 1995) or favoring conventional technologies before less developed ones (Bergek & Berggren, 2014). Since neither the regulatory organs nor the industry can predict future innovation, flexibility is important since it allows for the innovators to find technical solutions within a wider range (Johnstone et al., 2010).

3.5.4. Transparency

The Merriam-Webster dictionary defines "transparent" as: *"*a: *free from pretense or deceit, b: easily detected or seen through c***:** *readily understood, d***:** *characterized by visibility or accessibility of information especially concerning business practices"* (Transparent, 2015). In the context of building regulations and innovation, transparency translates to the regulation being based on confirmed principles of building physics (Rothwell, 1992), clear and comprehensible processes and not being overly complex (Gann et al., 1998). Transparency can also be related to a comprehensible assessment method that is not biased by different interest groups (Spiekman et al., 2010)

3.5.5. Enforcement

In Noailly (2012) enforcement is defined as monitoring and controls and in Kemp and Pontoglio (2011) it is associated with inspection and penalties for non-compliance. In Foliente et al. (1998) three different methods of verifying compliance in the context of a performance-based building regulation are given: by measuring, by calculating or by measuring and calculating. Based on the findings of Noailly (2012) and Ashford et al. (1985), a weak enforcement of a regulation reduces the probability that it will have a driving impact on innovation.

4. Results

In this chapter, the results of the desk study and the interviews are presented. The order is as follows: results of desk study on EP regulation in France, results of desk study on EP regulation in Sweden, results of interviews in France and results of interviews in Sweden.

4.1. Results of desk study

The aspects covered in the desk study include background and history of the EP regulation, EP requirement levels, method of compliance, approach to innovation and criticism against the regulation.

4.1.1. EP regulation in France

Like in many other countries, the first regulation regarding the energy consumption of buildings in France was developed as a reaction to the oil crisis in the early 1970's according to Guignard (2010). The objective was to decrease the independence of foreign oil and the vulnerability to rising oil prices. A limit on the total energy consumption of the building was imposed for the first time in French building energy regulation history with the RT (Réglementation Thermique) 2000 that came into full effect in June 2001. The objective of the RT 2000 was to reduce the energy consumption of dwellings by 20% and in tertiary buildings by 40% while ensuring thermal comfort in buildings without air conditioning. In order to conform to the EPBD the energy performance requirements of the regulations are to become stricter at least every five years (ibid.).

The RT 2005 was the first thermal regulation that came out after the EPBD first came into effect and the actions taken to comply with the directive resulted in a 20% increase in the regulatory requirements between 2000 and 2005 (Roger, Bonnemayre, Remesy & Menader, 2010). As soon as the RT 2005 came into effect the drafting of the next thermal regulation was started. The original objective was for the next energy performance regulation to come into effect in 2010. It was thus first referred to as the RT 2010 but due to the delay it was consequently named RT 2012 and came into full effect on January 1, 2013 (Roger and Remesy, 2012).

Energy performance requirements

The RT 2012 sets the primary energy target at 50 kWh/(m².year) for residential buildings and at 70 kWh/(m².year) for office buildings without air conditioning. This includes the energy used for heating, cooling, sanitary hot water production, lighting as well as ventilation auxiliaries (i.e. pumps and fans) in kWh/(m².year) (Roger & Remesy, 2012). The target is modulated depending on the building type, geographical situation, altitude, and greenhouse gas emissions of the energies used (MEDDE, 2011). Buildings that abide with the EP requirements of the RT 2012 are considered to be nearly zero energy buildings (Roger & Remesy, 2012).

Compared to the RT 2005 the energy consumption requirements of the RT 2012 are a big leap forward in terms of stringency, where the requirements have gone from a mean of 150 kWh/m².year in primary energy, to an average of 50 kWh/m².year. The future objective for 2020 is already set, with positive energy buildings that produce energy instead of consuming it (Roger & Remesy, 2012). According to the French authorities, the energy performance regulation has contributed to an important decrease in building's energy consumption compared to the expected energy consumption without a regulation in place (MEDDE, 2011). Information about future requirements is readily available on French government websites. An explanation to this quite dramatic tightening of the EP requirements can be found in the EPBD Country report from the end of 2012, when representatives from the Ministry of Housing and the Ministry of Environment write that *"France aspires to be the leading nation in EP policy, moving beyond the RT 2012, by setting new labels for the introduction of surplus energy buildings, which will be ready in 2020, despite the fact that the current regulations are already very ambitious"* (Roger & Remesy, 2012, p. 10)

The introduction of future EP requirements as a label is a tactic of stepwise tightening of the EP requirements that has been used before in France. When the RT 2005 was in force, the label BBC (Batiment Basse Consommation, Low energy consumption buildings) was introduced with the EP levels that corresponded to the future RT 2012 according to Roger and Remesy (2012)

Compliance and control

Compliance with the RT 2012 is based on a calculated energy performance value, based on standard use scenarios. The calculation has to be performed using software approved by the CSTB, with the RT 2012 calculation method, Th-BCE, integrated. Th-BCE is a development of the RT 2005 calculation method, which was criticized for relying too much on conventional scenarios and default input parameters. One of the challenges for the RT 2012 was thus to develop a calculation method that was closer to reality with an increased number of values entered by consultants and fewer default input parameters (Roger et al., 2010). This has resulted in a calculation method (Th-BCE) that covers 1377 pages, to compare with the RT 2005 calculation method that was only 159 pages. The objective of the Th-BCE calculation method is to describe all components of the building envelope and its energy systems. Since the RT 2012 sets a global energy performance target, architects and engineers have more freedom when designing the building and choosing equipment. Roger and Remesy (2012) state that the stringent requirements of the RT 2012 make the use of high performance equipment and envelope components necessary.

For certain HVAC products, the RT 2012 gives advantage to equipment that is certified under national or European certification schemes such as Eurovent or eu.bac. In some cases the use of performance values that are certified or tested can have an important impact on the final calculated energy performance result. For heat pumps for example, the COP/EER value is to be multiplied by 0.9 if the value comes from laboratory testing without certification, and by 0.8 if it is a value declared by the manufacturer. The lower COP value results in a higher energy consumption for the building in the regulatory EP calculation. If the product has a certification, such as Eurovent, the performance values specified in the certificate are used by the consultant performing the energy performance calculation. Another example of this is the certification of the control accuracy (CA) of the terminal regulation of heat/cold transmitters such as radiators, fan coils and climate beams. (Th-BCE, 2011) Most of the certified CA values are in the range between 0.1K and 0.4K (eu.bac, n.d.). If there is no certification, the default value of 1.8K is to be used in the calculation, which can increase the calculated energy consumption of the building with up to 20% according to Boisson (2010). A problem for some HVAC manufacturers is that the eu.bac certification is not available for all types of products, which means that they have a disadvantage compared to those products where a eu.bac certification is available.

During the elaboration process of the RT 2012 compliance and control was discussed since ambitious EP requirements are useless if it is easily possible to bypass the regulation in practice. When the RT 2005 was in effect, the estimated workaround rate for individual houses was somewhere around 50 to 60% according to Bataille and Birraux (2009). The responsibility of compliance with the RT 2012 is on the project owner (maître d'ouvrage). In case of non-compliance with the RT 2012 the project owner risks a fine of €45000 and even prison penalty (Article L.152-4 du Code de la construction et de l'habitation).

Innovation in French EP regulation

France is one of the member states that has developed an equivalence procedure for the assessment of innovations, referred to as Titre V. It is up to the manufacturer to prove the performance of the innovation and develop a calculation procedure for the innovation that can be integrated in the standard calculation method.

There is no technical framework describing how the equivalence study should be done as suggested in Spiekman et al. (2010), but the elements required to file a Titre V application are defined online on French authority websites. These include:

- A description of the system.
- Elements that prove its energy performance.
- List of inputs to be included in the standard calculation method.
- Detailed description explaining why the system cannot be assessed using the standard calculation method.
- A proposition on to assess the performance of the innovation that cannot be assessed by the standard calculation method.
- On-site measures from existing building proving the real energy performance of the innovation. (MEDDE, 2013)

The Titre V application is submitted to the Ministry for Ecology, Sustainable Development and Spatial Planning for evaluation and once accepted, it becomes part of the regulation. Accepted Titre V calculation procedures are then published online and can serve as an example for future equivalence studies.

Criticism against the French EP regulation

Some stakeholders are of the opinion that the RT 2012 calculation method is too complicated, and in a report from a working group to the Minister of Territorial Equality and Housing, Bouyer (2014) proposes a simplification of the calculation method is in order to make it clearer, more comprehensible, more reliable and less complex. According to Bouyer (2014), in the current method certain parameters and even the order in which they are entered in the software can have a surprisingly large effect on the final energy performance results in a regulatory calculation. This makes it difficult for the consultant performing the calculation to comprehend the effects that modifications of choices in the conception of buildings can have on the energy performance calculation in the software. The report also mentions the complexity of the calculation method as a barrier to innovation of industrial products. A reason to simplify the calculation method is that the products of today are a lot more complex than before, and by simplifying the calculation method a certain margin of error can accepted when simulating the energy performance of innovations.

4.1.2. EP regulation in Sweden

The first national building regulation in Sweden, BABS 46, came into effect in 1947 (Boverket, n.d.). It included prescriptive requirements on ventilation and maximum allowed U-values for walls, slab, roof and windows as well as a method for calculating the U-values. BABS 46 was updated in 1950 (BABS 50) and 1960 (BABS 60). In 1967 the regulation SBN 67 (Swedish Building Norm 67), came into effect. SBN 67 was updated in 1975 and 1980 and strived towards functional requirements instead of prescriptive requirements. A supplement to SBN 75 concerning energy efficiency came out in 1977, 4 years after the oil crisis. The supplement introduced requirements on thermal comfort, indoor air quality and air tightness of buildings. In 1989 SBN 80 was replaced by NR 1 (Rules for new construction 1). NR 1 specified an average U-value for the building envelope instead of requirements on each element, thus allowing for more freedom in the building design (Boverket, n.d).

Boverket, (the Swedish National Board of Housing, Building and Planning), is the authority responsible for elaborating the technical building regulation in Sweden. In the technical building regulation there is a section about energy management. The first version of the current regulation, BBR, (the Building Rules of the Swedish National Board of Housing, Building and Planning), came into effect in 1994. BBR are functional rules that are reviewed and updated continuously, and include mandatory requirements and general advice. The first version of BBR specified a lowest allowed average U-value of the building envelope and defined how this was to be calculated. In the given calculation method, solar radiation, thermal bridges and the heat storage of the ground were accounted for (Boverket, n.d).

A major change in terms of energy management appeared in BBR 12 of 2006: the minimum requirements on the energy performance of buildings as required by the EPBD were introduced instead of requirements solely on the buildings’ energy losses. Since 2006, BBR requires that buildings shall be designed to ensure that the specific energy use of the building and that average thermal transmittance (U-value) of the building envelope do not exceed specified maximum values. According to Boverket (2006) this increases the possibility of choosing different technical solutions and promotes technical evolution.

Energy performance requirements

When EP requirements were first included in BBR in 2006, there were only two climate zones: north and south. According to BBR 12, buildings were to be designed in such way that the specific energy use for dwellings in the north did not exceed 130 kWh/m^2.year, and in the south 110 kWh/m^2.year. The number of climate zones was later increased to three. The EP requirements in BBR 21 from 2014 depend on the climate zone, if the building is to be used for housing or not, and if the building is heated by electricity (see table below). The requirements in BBR refer to the measured energy used for heating, cooling, hot water and auxiliary energy of the finished building that is then divided by the heated area (Karlsson-Hjorth & Johansson, 2012). According to Boverket (2012) an energy performance calculation performed in the design phase of the construction project needs to have a safety margin in order to be sure that the energy use of the finished building does not exceed the EP levels specified in the table below. Unlike the French regulation, the requirements in the Swedish regulation are based on bought energy and not primary energy (Karlsson-Hjorth & Johansson, 2012).

Table 2. Energy performance requirements of BBR

Climate zone		I	II	III
Dwellings that have a heating method other than electric heating	Building's specific energy use, BBR 21 (kWh/m^2.year)	130	110	90
	Previous requirement, BBR 18 (kWh/m^2.year)	*150*	*130*	*110*
Dwellings with electric heating	Building's specific energy use, BBR 21 (kWh/m^2.year)	95	75	55
	Previous requirement, BBR 18 (kWh/m^2.year)	*95*	*75*	*55*
Premises that have a heating method other than electric heating	Building's specific energy use, BBR 21 (kWh/m^2.year)	120	100	80
	Previous requirement, BBR 18 (kWh/m^2.year)	*140*	*120*	*100*
Premises with electric heating	Building's specific energy use, BBR 21 (kWh/m^2.year)	95	75	55
	Previous requirement, BBR 18 (kWh/m^2.year)	*95*	*75*	*55*

The EP requirements were tightened in 2011 with BBR 18, and according to Boverket's website they have the intention of tightening the EP requirements with about 10% in all climate zones from February 1st 2015 (Boverket, 2014a). Before a revision of the regulation, Boverket has to analyze the economical, technical and environmental consequences and the impact of the change on children elderly and disabled. The EP requirement levels are based on what is economically feasible with existing technology, and the evolution of low energy buildings is continuously monitored to see how the requirements can be tightened in the future (Karlsson-Hjorth & Johansson, 2012).

Calculation method

Unlike France and most other member states, Sweden has not developed an EP regulation calculation method. In a consequence report concerning a revision of BBR from 2011, Boverket writes: *"The way of calculating the energy and using input parameters falls outside the scope of BBR. This is because the regulatory requirements are based on the finished buildings measured actual energy consumption and not a calculated value. The calculation tool and the input parameters must be based on the level of quality and construction technique used by the project owner/contractor/consultant"* (Boverket, 2011, p. 9)

Compliance and control

In chapter 9 of BBR it is advised that the calculated energy use values should be verified by measuring the actual energy use of the completed building, and buildings are required to be equipped with a measuring system making it possible to follow up the energy use of the building (Boverket, 2014a). The control authority for EP requirements is the building board of the municipality. Compliance is based on two steps: an EP calculation during the construction process and a verification of the actual energy consumption of the building, which is to be done during the second heating season of the building according to Karlsson-Hjorth and Johansson (2012).

The control of a building's EP can be coordinated with the establishment of an energy performance certificate, since the law requires that a building needs to have an EP certificate two years after it's taken into use at the latest and the energy performance of the building is to be declared in the same format for the EP certificate and the BBR requirements (Boverket, 2012). Boverket took over the role as compliance checker of EP certificates from local authorities in 2007, and has established a central register for EP certificates in order to increase the rate of compliance (ibid.).

According to an investigation by Boverket, almost 60% of buildings constructed between 2007 and 2012 do not live up to the energy requirements in BBR. The investigation was done by looking through the measured energy performance values in the EP certificate registry of 2000 new buildings (Bengtsson, 2014). The result of this investigation has served as a support for the new EP requirement levels according to Rosén (2014).

Innovation in Swedish EP regulation

According to Boverket (2010), the shift to functional requirements on the EP of buildings in BBR gives the building designer almost unlimited options of how to reach the requirements, which increases the possibility of choosing a cost-efficient innovative solution. According to Boverket functional requirements *"promote technological development and make the use of innovative solutions possible"* (Boverket, 2006, p. 15).

In a report from 2014, Boverket states that more stringent EP requirements is likely to drive the environmental technology development forward. This supposition is based on the Porter hypothesis (see p.20) and strengthened by recent research claiming that energy policy instruments that are flexible and stable in the long term may very well generate innovation (Boverket, 2014b).

Criticism against the Swedish EP regulation

According to Nässén, Sprei, and Holmberg (2008) the EP regulation requirements are an important factor for energy investments in construction of new buildings. They found that Swedish regulation had become more of a norm than minimum requirements. In terms of stringency it had only been slightly strengthened since the 1970's. This means that the regulatory incentive for the building sector to pay for more energy efficient buildings was very small (Nässén & Holmberg, 2005).

After the tightening of the EP requirements in BBR in 2011, Boverket received criticism from actors in the building sector, the Swedish Energy agency and researchers claiming that the requirements are not strict enough. The construction and real estate sector in Sweden can live up to tighter requirements (Dahlquist, 2011a). According to the Swedish Building Industry association, the laxity of BBR implies that buildings built today will not be efficient enough to contribute to the Swedish parliament's objective of cutting the energy consumption in half by 2050. There is also a difference between the objectives of Boverket and the Swedish Energy Agency, creating insecurity about how ambitious the future EP requirements will be (Dahlquist, 2011b)

Concerning the latest update of BBR that was sent out for referral in 2014, Swedisol, the sector association for the building insulation industry was of the opinion that the proposed tightening of the EP requirements will reduce the energy consumption of buildings but only down to the average of buildings constructed today. In order to deal with the climate and energy change, Swedisol state that we need building regulations that push the evolution forward. According to them the EP requirements could be tighter than proposed in order to correspond to what is technically and economically possible today. Swedisol also expressed criticism towards the lack of openness in the revision process, and stating that the actors of the building sector should have been involved to a larger extent (Swedisol, 2014). The sector association for the ventilation companies was also of the opinion that Boverket could have gone even further in tightening the EP requirements. According to Svensk Ventilation, the development of energy efficient ventilation products and methods takes a long time. Therefore the Swedish ventilation technology and installation companies need to know as soon as possible what the EP requirements will look like in 2020 when all buildings are supposed to be nZEB (Svensk Ventilation, 2014). This was also brought up by the building contractor's sector association, emphasizing the need for predictability of the long-term development of the energy performance requirements. They propose that Boverket presents a prognosis for the planned tightening of the EP requirement levels so that the actors of the building sector have time to adapt their production (Byggherrarna, 2014).

A Swedish heating, ventilation and plumbing sector association claim that the proposed EP requirement level means that Sweden will not reach its energy and environment goals, and that there is a risk that large and fast changes in the regulation will lead to increased construction costs (VVS Företagen, 2014).

4.2. Interview results

The results from the second data collection method, expert interviews, are presented below. First, the results from the three interviews in France (interviewees A, B and C) and then the results from the interviews in Sweden (interviewees D, E, F and G). For each country, the results from the interview with the authority representative are presented first, then the HVAC association representative and last the consultant. The interviews aim at providing knowledge on the energy performance regulations in France and Sweden from the point of view of someone with professional experience.

4.2.1. Interviewee A: Actor working for the authorities in France

Interviewee A was responsible for the Energy Performance of Buildings Department at the laboratory that serves as the technical aid to the French authorities. The team consists of 11 persons who dedicate half their time to the EP regulation and developed the regulatory calculation method, called Th-BCE and the associated computing code.

Elaboration of the EP regulation

According to interviewee A it was decided to revise the previous regulation, RT 2005, in order to increase the EP requirements related to the construction of new buildings. The work with developing the RT 2012 started in 2008 in cooperation with the Ministry of Housing. The regulation was revised completely and a primary step in the process of revision was forming working groups with professionals from different actors in the construction sector. The working groups were organized in a way so that all actors in the construction sector could take a stand regarding the new regulation in terms of constructive systems, energy systems, energy performance and also the RT 2012 calculation method. The working groups met 2-3 times which resulted in a first draft of the RT 2012. The first draft consisted of a paper version of the calculation method to make it more explicit as well as a software tool with the calculation method implemented. The authorities organized user groups that tested the software and helped debug and define requirement levels. According to interviewee A, the calculation method is now robust enough to last many more years and the software tool can be adapted to future strengthened EP requirements.

General approach

Interviewee A explained that it was decided to include practically all input parameters linked to the building and its energy systems in the calculation method. This was based on the decision to a performance based EP regulation, making rather meticulous and detailed input parameters necessary. This means that there are a large number of input parameters, but according to interviewee A the consultants that perform the EP calculations are familiar with them. Interviewee A acknowledged that the RT 2012 can appear complex when applying it which could be perceived as a brake to the use of the calculation tool but today, two years after its introduction, the consultants have had time to make sense of it. When asked about the future evolution of the complexity level of the regulation, interviewee A stated that it will not be made more complex, if anything the number of input parameters will be reduced.

Compliance and controls

According to interviewee A compliance with the French EP regulation is based on calculated EP values, since the building is generally not built yet when a regulatory calculation is performed. Interviewee A explained that certain standard scenarios are used in the EP calculation to represent for example the weather. The standard scenarios are used to perform a calculation that is as close to reality as possible, but once the building is in use the energy consumption will evidently differ from the calculated values since for example the weather and the number of persons in the building will be different. Interviewee A stated that the RT 2012 is an estimative regulation whose mission is not to depict the real energy consumption of the finished building, but it is nevertheless very close to reality. In terms of controls of compliance with the regulation, there are unexpected controls of some buildings by accredited local government officers. Only about 1% of new buildings are verified every year since the authorities lack the means of performing more controls.

Approach to innovation

The products that are already included in the standard calculation method were chosen based on what was common in the beginning of 2010 according to interviewee A, and some products have been added with time. For innovations interviewee A referred to the Titre V procedure: innovations are included in the regulation once a manufacturer does the Titre V procedure. The Titre V was introduced with the RT 2005, but the computer software limited the possibilities of integrating innovations. Within the software platform of today, innovations can be completely coded. According to interviewee A, the big novelty of the RT 2012 compared to RT 2005 was that innovations can be completely integrated in the computer code.

Interviewee A mentioned that there is a process in place in France in order to reduce the number of norms and regulations and for the RT 2012 there is a need to reduce the time it takes to treat a Titre V application. At the same time, interviewee A stated that there is a need for a certain time to study the application in order to make sure that the quality of the RT is maintained.

In terms of impact on innovation interviewee A stated that the tightened EP requirements have forced the industry to innovate more energy efficient products in order to comply. The level of complexity was also found to have an important impact on innovation since the tight overall energy requirements make it necessary to use innovations that make it possible to make energy saving in the HVAC system and the building.

4.2.2. Interviewee B: Representative for industrial association in France

Interviewee B is an energy engineer who has been working as technical manager of ventilation and air handling at a French HVAC syndicate for 7 years. The syndicate brings together 86 HVAC manufacturers representing almost 80% of the market. The tasks of interviewee B include being á jour with the regulation in order to be able to help the members of the syndicate in making sure their products are in line with the regulation but also working towards the public administration to influence the regulation so that the regulation concurs with products already present on the market as well as future products.

Elaboration of the EP regulation

The syndicate participated in the elaboration of the RT 2012, but interviewee B explained that their opinion did not carry as much weight as the opinion of for example those representing the interests of the building structure and building envelope that are a lot more influential.

Interviewee B explained that France anticipated the first EPBD from 2002 by two years and started reviewing their building energy regulations in 2000 when the Réglementation Thermique 2000 (RT 2000) came out. Since then, a new, revised version has come out every 5 years which is related to the EPBD requirements of reviewing the building regulations at regular interval no longer than 5 years. This is a significant shift, because before the RT 2000 the last regulation came out in 1989 and before that in the 1970’s. Interviewee B stated that adapting to a new regulation every five years is quite a challenge for the different professionals in the building sector, who have to learn to produce projects that are conform with the new requirements often.

General approach

According to interviewee B, France has historically built houses with very bad energy performance, with no insulation and old heating systems. Therefore, the true energy savings can be made in renovating the existing buildings. Due to the economic situation though there is a lack of funds in both the public and the private sector which means that it is not possible to take action to improve the energy performance of existing buildings. In France today, interviewee B talked about “the thermos effect”, with buildings that are more and more air tight.

In the RT 2012 calculation method, there are certain information gaps concerning for example which values should be entered. According to interviewee B, consultants often enter the default value because they don’t know which value they’re supposed to enter. This is why the HVAC syndicate and other actors as well have published “guides de saisie”, guides explaining how to enter a certain product or solution into the RT 2012 calculation.

Interviewee B gave the example of a coefficient for the power of the fans in an air handling unit. The coefficient is to be entered in the calculation software but is not explicitly described in the Th-BCE calculation method. The HVAC syndicate has made a guide to show what value should be entered and has proposed to the authorities that the guide can be used as an official document but so far this has not happened.

Interviewee B stated that the language of the RT doesn't always correspond to the language of the industry and there was a need for guides making the link between values declared by manufacturers and input values demanded by the RT. The syndicate has perceived that there were large differences between consultants in how entered the characteristics of HVAC equipment in the regulatory calculations. Consequently, the energy performance of some HVAC products is not taken into account to a full extent in the RT 2012 calculations.

According to interviewee B, professionals in the construction sector criticize the RT 2012 since the summer of 2013 claiming that it is too complicated, too restrictive and costs too much. Interviewee B stated that the EP regulation is a blockage to new construction since it is too complicated and makes construction too expensive. France went ahead too quickly with the EP regulation and the construction sector has not been able to keep up. The response from the authorities has been simplification in order to revitalize the market. They have released "50 measures of simplification of the technical building regulations", where they have looked over what makes the regulations so costly.

Approach to innovation

According to interviewee B a demand for a Titre V can be made either by a manufacturer or by the public authorities. Interviewee B wrote in a complimentary response that the HVAC syndicate is positive to improving the Titre V procedure so that new products can be included in the RT 2012 while at the same time maintaining the requirement level of the EP performance criteria. To a product or solution that is not included in the RT 2012, the regulation is a market barrier; it cannot be sold in France without a Titre V according to interviewee B. This is why the HVAC syndicate has worked with the public authorities on Titre V applications for products that were in the RT 2005, but not included in the RT 2012 at first and products that may not be a large part of the market in France at the moment. The syndicate wrote to the authorities concerning products that were included in the RT 2005 and then omitted from the RT 2012 even though they were still present on the market. The authorities undertook the development of Titre V for these products at their cost to correct this incoherency. Interviewee B also explained that they have shown that it is important that the regulation does not become a market barrier to products that are part of a niche market with low volumes sold in France today but are part of a bigger European market. If these products make it possible to respond to the energy challenge in the future, and the HVAC syndicate has members that manufacture them, they need to be in the regulation as well according to interviewee B.

According to interviewee B the problem in France is not the innovation, it is the building sector that is not ready to accept innovative solutions. Interviewee B stated that the construction sector in France is not structured like in other countries and it may not be as skilled and qualified as in other countries such as Sweden or Germany. According to interviewee B, the building sector in France is about reaction and not prevention, there are controls, but no anticipation. Many innovative solutions have come out, but the sector has not been ready and hasn't known how to calculate, dimension and install the innovative solution.

According to interviewee B the requirements of the RT has encouraged the use of more energy efficient HVAC products, and there has been a significant evolution in the supply of products with high energy efficiency. Interviewee B states that the market is still using traditional solutions, but with higher energy efficiency. In terms of ventilation though, there has been no impact of the RT on innovation because France has had the same regulation for ventilation since the 1980's when the humidity controlled ventilation came out and they have been sticking with the same system since.

4.2.3. Interviewee C: Consultant working with the energy performance of buildings in France

Interviewee C is head of studies at a French engineering consultant firm. Interviewee C has worked there since 2008, at first with the RT 2005 and since one or two years back with the RT 2012.

General approach

The RT 2012 is described by interviewee C as quite heavy and tedious, but very structured. According to interviewee C there is information to be found and help for the software that is quite coherent so the consultants are not lost. The difficulty is that the calculation rules are not always very clear. Interviewee C finds that the French EP regulation is effective for reducing the energy consumption of buildings since everyone has to comply with the same requirements. This is especially important during a financial crisis period, since the goal is to construct at the lowest cost possible. Without regulation there would be competition issues between those who take energy performance issues seriously and those who don't, with large differences in energy performances and incomparable construction costs.

Application

Interviewee C explained that the standard regulatory calculation method makes it possible to compare the energy performance of buildings on a common base, for example using the same indoor temperature. If the regulation did not define an indoor temperature for the EP calculation, low indoor temperatures would be used for the calculation resulting in a low calculated energy consumption but higher energy consumption in reality. According to interviewee C, the calculated regulatory EP values are relatively coherent with reality for residential buildings. For tertiary buildings the challenge is that the RT 2012 only takes into account heating, cooling, lighting, DHW and fans whereas in reality computers etc. consume as much energy. Interviewee C saw this as one of the limitations with the RT 2012.

The calculation method demands certain performance values of HVAC equipment, such as the COP of a heat pump. Interviewee C stated that it is up to the manufacturer to provide the consultant with correct values and if the controller sees the technical specifications from the manufacturer it is not necessarily verified if these are correct or not. The final EP calculation result is published online on the website *www.rt-batiment.fr* and should be accessible for authority control agents up to 5 years after the building is delivered.

Compliance and controls

According to interviewee C, compliance with the regulation is controlled by government officials, and the controls will be reinforced with the RT 2012. There is already a project owner that has been prosecuted for reasons of non-compliance with the EP regulation. The government officials have the right to control the building up to three years after it's been finished. They control that the equipment that has been installed in the building are the same as the ones that were used for the regulatory calculation.

Approach to innovation

According to interviewee C, the EP regulation has led to an evolution in the HVAC sector. The RT has brought along technologies that were just emerging ten years ago, making them standard solutions today. Without regulation there is no incentive for the manufacturer to innovate since it costs money, making the product more expensive and difficult to sell. The RT 2012 obliges the manufacturers to make products that are more energy efficient, which decreases the costs in the long run when they become standard solutions. Interviewee C named multiple examples of technical evolution that has taken place in France thanks to the EP regulation.

Interviewee C claimed that it is rare today to come across equipment that is not taken into account in the EP regulation, due to the number of Titre V that have been published. A Titre V for an innovative system means that the product will be certified and validated after verification by an expert commission that convenes once a month. For complex systems the commission often has questions on the calculation method proposed in the Titre V application. The application can be sent back and forth between the manufacturer and the commission many times before being validated. Normally the manufacturer knows the innovation best, and it is necessary that the application is clear so that the commission can pronounce a judgment quickly. Once validated, the Titre V will result in a modifying decree of the Th-BCE, which means that it really becomes part of the regulation. According to interviewee C the Titre V approach could be ameliorated by reducing the delay for validation but acknowledges that due to the increasing complexity of the systems validation will always take a certain time. The waiting time for validation of a Titre V application usually ranges from 6 months to 1,5 years.

4.2.4. Interviewee D: Actor working for the authorities in Sweden

Interviewee D works at the Division of Sustainable Buildings at the Swedish National Board of Housing, Building and Planning (Boverket).

Elaboration of regulation

Interviewee D explained that the current EP regulation in Sweden, BBR, has been elaborated over a long period of time. The decision to have functional requirements instead of detail requirements was made partly to increase the possibilities for innovation but also because detail requirements require a lot of personnel. Boverket has been given the task of elaborating methods of verification of the functional requirements, which is not so easy.

Before 2006, interviewee D stated that there were requirements that the building envelope had to be a certain way and its performance had to be calculated according to a certain standard. When these calculations were followed up, interviewee D stated that the real energy consumption of the building could be up to 250 % higher than what was calculated. There was a paradigm shift in Swedish building regulation in 2006, after the EPBD came into effect, from basing compliance on requirements on the building envelope to requirements on the measured energy performance of the finished building. Energy calculations are still made along the way, but the final method of verification of the building's energy performance is the measured energy use of the finished building.

General approach

The Swedish regulatory approach was described by interviewee D as pragmatic. Instead of having a calculation method defining the building down to the smallest detail, compliance with the Swedish EP regulation is based on measurements of the finished building's energy use. According to interviewee D this means that Sweden avoids a lot of problems experienced in other countries related to complicated building forms and systems. Interviewee D stated that the main difficulties in Sweden are for the building planners who have to be able to design the buildings that will be conforming to BBR. What the planners usually do is base the calculations on the climate in the northern part of each one of the three climate zones and use a security margin. In the colder part of the climate zones, the buildings are usually about 10 % better in terms of energy performance than BBR, and in the southern part of the zone they may be 35-45 % better than the building regulations.

According to interviewee D, the mission of Boverket is to write the minimum requirements of society but there is nothing preventing the industry from constructing more energy efficient buildings. Interviewee D acknowledged that there is some pressure from the construction sector who wants Boverket to put the foot down and say "the requirements for 2020 will look like this" because they want time to adapt their production machinery. The government has appointed some investigations with the objective of determining by year 2015, how far it is possible to get. Boverket is involved in three projects in collaboration with the Swedish Energy Agency that are related to low energy buildings, energy measuring, demonstration projects and support to those who build low energy buildings.

Interviewee D mentioned that Boverket is obliged to make an "analysis of consequences" with every modification of the EP regulation, where the economical consequences for society and real estate are investigated. The best is of course if the modification is beneficial both for society and the construction sector, but if a modification is found to be very beneficial for society support can be given to the sector to compensate.

Concerning the EPBD requirement of nZEB, interviewee D said that *"it sounds like they should be very close to zero, but if one looks at the energy used in buildings today it may not be possible to get close to zero. It is possible to achieve buildings with a very high energy performance, but they are leading-edge projects with more goodwill profits than anything else"*.

Compliance and controls

The enforcement and verification part is a weak link with the Swedish regulatory system according to interviewee D, because the responsibility of verifying the compliance is the responsibility of the building board of the municipalities. Boverket does not have the right to depict what the municipalities should do, but they recommend that the municipality oversees the EP calculations from the consultants (that can be made using any calculation method) to see if they seem reasonable or not. If they are deemed by municipality officials to be reasonable, it can be left at that. The other option is to wait until the building is finished, and allow that it is taken into use until the energy consumption of the last 12 months of the first two years has been measured. One year is allowed for the building systems to be calibrated, concrete to dry out etc., which is why the energy consumption is measured the second year.

Whether the energy consumption of the finished building is measured or not depends on if the municipalities ask for it. The energy performance declaration is supposed to be done at the same point in time as the EP regulation energy consumption measurement, so if the municipality knows the building contractor very well they may not require that the energy consumption is measured and focus on other requirements. In the end it is the responsibility of the building contractor that the building lives up to the requirements in BBR, whether the municipality has asked to verify this or not. There is work in progress with giving the municipalities access to the directory of energy declarations so that they can see whether the declared buildings comply with the requirements in BBR or not.

On the subject of measuring the energy consumption of a building, interviewee D explained that the difficulty depends on the type of energy. For district heating in urban areas, where the energy that goes out to the substations is measured, it can be difficult to know exactly how much energy goes to each building. According to interviewee D though, the experts doing the energy declarations should know how to calculate the distribution to each building.

Approach to innovation

Interviewee D stated that if a specific calculation method is defined for the EP regulation, and an alternative way of doing things is discovered, one has to go back to the calculation method and maybe even modify it. This means that the Swedish approach is rather beneficial for innovative solutions according to interviewee D, since the performance of the innovation can be proven by a lower measured energy use and is not affected by a predefined calculation method.

4.2.5. Interviewee E: Representative for industrial association in Sweden

Interviewee E is the technical and environmental manager at a ventilation industry trade association in Sweden and has worked there for 2,5 years. The trade association is dedicated to technical and business matters in the ventilation sector and works a lot towards policy makers and company leaders to promote their three main causes: indoor climate and health, building energy efficiency and recruiting to the sector. For the second cause, the task of the association is to stress the important role of ventilation in achieving buildings with high energy performance.

Elaboration of regulation

The trade association is one of the participants in the construction council of Boverket whose opinions are taken into consideration for future modifications of BBR. According to interviewee E the trade association has a close cooperation with Boverket. The trade association is a body always consulted for proposed legislation modifications (remissinstans), and they always respond. When it comes to the significance of the ventilation sector, the interviewee thinks that it has a pretty strong position, and referred to the fact that BBR has a chapter directly related to ventilation. There is one air and indoor climate expert at Boverket though, compared to maybe 20 experts on energy due to the authorities' focus on energy issues. In BBR both health and energy requirements are essentially set on a systems level, for the whole house/building. For building modifications there are specific requirements for windows and insulation but for ventilation products Boverket does not set any specific energy efficiency requirements on the products except maybe specific fan efficiency, which is efficiency is dependent on the system.

General approach

Interviewee E deemed the impact of the EPBD on the Swedish building sector as indirect, since the Swedish building sector looks at the Swedish building regulation. The companies may look to the EPBD and see that there is a driving force to change the Swedish building regulations, but the "rules of the game" in Sweden are set by Boverket. Interviewee E stated that the EPBD can be used for lobbying purposes in order to show that the requirements need to be strengthened.

Interviewee E mentioned that the energy requirements for buildings will be tightened in the beginning of 2015. The ventilation sector has always been positive to strengthening the energy performance requirements, because it plays into the hands of the ventilation industry. "*Without good heat recovery via the ventilation system it is difficult to achieve high energy performance. Our technology becomes a key to achieving the stricter energy requirements"*. The interviewee points out though that their association includes installation companies, and even though they too want stricter requirements, going too far and setting requirements that are too hard to realize can have a negative impact.

Application

HVAC manufacturers reacted on false claims of high energy efficiency values of competitors. To deal with this, the trade association has published guidelines for how the energy efficiency of ventilation products should be presented, in order to assure that all manufacturers use the same humidity and temperatures. Otherwise a manufacturer can claim that for example their air handling unit has a heat exchange efficiency of 99% that in reality is less efficient than a declared 89% from another manufacturer. It is up to the municipalities' building board to supervise this, and to interpret and follow up that this is followed in theory but also through measurements. The interviewee states that users' behavior (such as a lot of showering) could possibly be used to explain why the building does not live up to the energy requirements.

A long-term goal of the trade association is for product requirements to become a regulatory requirement, or even better: that the customer demands it. The interviewee doubts that it will become a regulatory requirement due to the liberal approach of the Swedish regulation but has bigger hopes that energy performance certifications can become a requirement in public procurements.

4.2.6. Interviewees F and G: Consultants working with the energy performance of buildings in Sweden

Interviewees F and G are colleagues at an engineering consultant firm in Sweden. Interviewee F works mainly with installation systems in energy efficient buildings and operation monitoring, but also with highlighting the issues with installation systems, how their performance should be assessed and how good their performance can get. Interviewee G works with energy related issues in general since the end of the 1970's and has worked as a lecturer at the Royal Institute of Technology for 10 years on the subject of building technology and energy use. Interviewee G has been involved in the SVEBY project, a project that aims at standardizing the verification of the energy use in buildings. Both interviewees have performed postgraduate studies.

Elaboration of regulation

Concerning the SVEBY project, interviewee G describes it as an initiative taken by major actors in the construction sector in order to develop industry standards for how to assess and verify the energy use of buildings. The objective is to get everyone to calculate the energy performance of buildings the same way, measure the same ways and verify the measurements the same way. The original reason why a defined calculation method is not part of the Swedish EP regulation is because there were many different energy calculation software available at the time. They held a strong position and the market had spent a lot of time and research money on developing them. Choosing one of the existing software was not desirable, and developing new software was too demanding at that point since it had been decided to use measured values for both the energy declarations and the EP regulation. The choice to use measured values is quite the contrary of most other European countries that base their regulation on "standardized use" scenarios and energy performance calculations. According to interviewee G Sweden had that approach at first, but saw that there were large differences between the calculated and actual energy use of the buildings, a lot of optimistic energy calculations. With the measured energy approach, the building has to live up to the calculated EP as well!

General approach

Both interviewees agreed that the EP regulation in Sweden is not the main driving factor for reducing the energy consumption of buildings. Interviewee G stated that the regulation is more there to oblige the worst to higher their level, and according to interviewee F environmental certification schemes are more of a driving factor for the energy efficiency of buildings. According to interviewee G, there are always frequent changes to BBR and there is uncertainty concerning where the quantitative EP requirement of BBR will land. Interviewee F said that the construction sector has demanded a ladder depicting the future tightened requirements. There was a hearing and after that a preliminary ladder proposition came out, but it was only a proposition with preliminary quantitative EP requirements illustrating what levels Boverket aspired at achieving.

Approach to innovation

In order to prove the performance of innovative products, interviewee F refers to reference projects. Before investing, it is preferred to see someone else who has chosen a similar solution with a similar building. For this purpose, it is an advantage to have measured values showing that the innovative solution works as intended. It is therefore important that it is easy to obtain measured values indicating how it works. According to interviewee G it takes a long time to release a product, but it is a good thing that there is a filter for products that are not compatible with our building regulations. The regulation had a more important impact on innovative products before, when "type approvals" guaranteeing the performance of certain components were used by Boverket. Today it is more unclear how to prove the performance of new products according to interviewee G, because there are more testing bodies and *"you get a feeling that you get the values that you pay for*".

In terms of development of the HVAC sector the last ten years, the interviewees named air handling units (AHU) with integrated controls systems. The main reason for this is mainly because the manufacturers want to be able to oversee what happens in the AHU without having to send out a technician according to interviewee F. Interviewee G named the requirements from the clients who demand a certain energy performance as an evolution. This demand from the clients makes it necessary to know that for example the energy recovery in the AHU works as intended. For example Skanska (one of the biggest construction companies in Sweden) has started doing more following up on the energy use of buildings, which requires more meters and possibilities of logging the data. According to interviewee G, the building sector is far behind for example the auto industry, where cars are equipped with a standardized output where the Motor Vehicle Inspection Company has access to all values. With more stringent energy requirements and smaller margins, it becomes more necessary to be able to oversee the subsystems in the building according to interviewee F. With access to some measured values, it is possible to see if a building component is not working properly and go back to the manufacturer and ask why their product is not working like it should. It could be related to changes in the conditions for this component such as temperature or pressure leading to an unexpected energy performance.

Application

Interviewee F named numerous cruxes with measuring the energy consumption of a building. There could be other things on the meters such as engine pre-heaters and misconnections occur. The last difficulty is the fact that due to delays in the construction process, the deployment of all HVAC systems is not given enough time, meaning that the systems may end up not being calibrated correctly. According to interviewee G, the companies that are supposed to verify the energy measuring results are too uncritical, and just happy that some number comes out of the measuring. There could be errors with the measuring, but interviewee G states that it is more just a matter of checking a box and saying “it looks good”.

For an energy declaration, it is important that the right things are measured and that one knows for example how many houses’ energy is measured with a certain meter, which can be tricky according to interviewee G. It can be difficult to draw the line between the building energy and the household and activity energy. Part of the SVEBY project was about defining what should be included in the measured value. This has been defined for offices and dwellings so far. Despite the difficulties associated with measuring the energy use of a building, even more detailed input data would be necessary for an energy calculation.

Compliance and control

In terms of enforcement, interviewee G stated that all new buildings are to be checked for compliance with the EP regulation within two years of it being finished and all existing buildings should be checked via the energy declaration. Technically, non-conform buildings could result in some kind of sanction, but interviewee G has never seen this happen. About 75% of buildings are declared; maybe more when it comes to new construction since the municipality’s building council is still present there.

4.3. Summary of interview results in France and Sweden

The results of the interviews with interviewees A-G are summarized in the figures below.

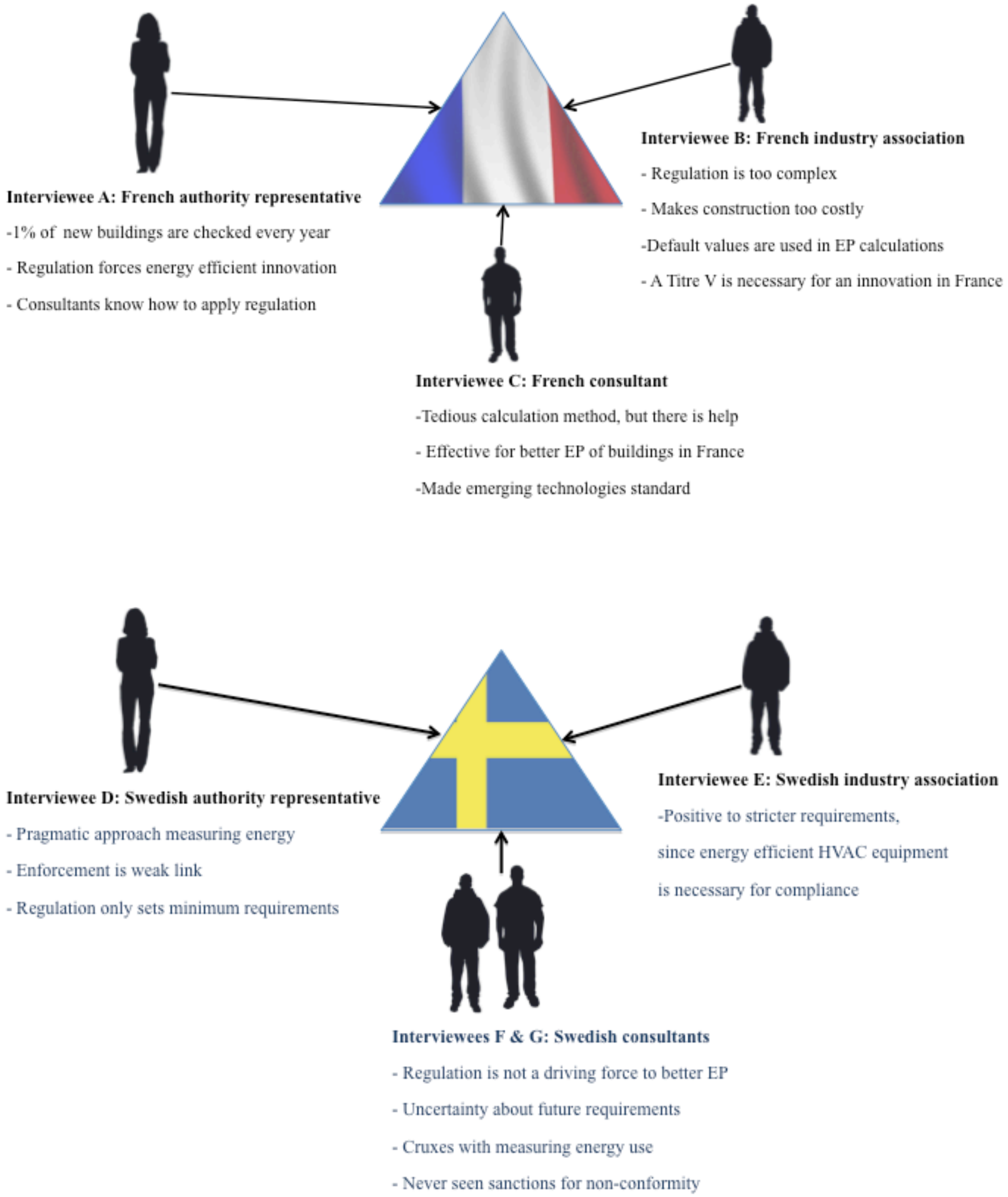

Figure 4. Summary of interview results France and Sweden

5. Analysis

In this chapter, the results from the desk study and the interviews are analyzed using the five regulation design characteristics defined in the theoretical framework (stringency, certainty, flexibility, transparency and enforcement). The results from France and Sweden are first analyzed separately for each characteristic and then compared to each other.

5.1. Stringency

5.1.1. Results France

The desk study revealed that France aspires to be the leading nation in EP policy and the French authorities seem to pride themselves on being ahead of what the EPBD demands. The EP requirements have been tightened from 150 to 50 kWh/m^2.year between 2005 and 2012. According to the theoretic framework for this thesis, the high stringency level of the French EP regulation can be expected to increase its driving effect on HVAC innovation, since the demanding EP requirement levels are difficult to reach without energy efficient HVAC equipment.

The French interviewees identified the French EP regulation as a major driving factor towards both more energy efficient buildings and of energy efficient building components becoming standard. On the negative side, interviewee B from the HVAC association claimed that the building regulation was a major block to construction making it too expensive to build, which could have a negative impact on innovation since it reduces the demand in the construction sector as a whole.

5.1.2. Results Sweden

The desk study showed that in Sweden the tightening of the quantitative requirements of the EP regulation has not been as important as in France, and the requirements are barely more stringent than in 2006 when the energy performance approach was first introduced. The Swedish construction sector has indicated that they want more stringent EP requirements, which suggests that the stringency levels of Swedish EP regulation are not very demanding.

The answers from the interviewees from Sweden give a concordant picture of the stringency levels in the Swedish EP regulation. Interviewee D who works for the authorities stated that their mission is only to set the minimum requirements of society. The consultants' (interviewees F & G) claim that the EP regulation is not a key factor in reducing the energy consumption of buildings and the HVAC association representative's positive attitude towards tightened EP requirements contributes to the idea that the Swedish EP regulation is not very stringent. The Swedish consultants (interviewees F and G) further stated that the push towards more energy efficient HVAC products and more energy efficient buildings is expected to come from the market and different labels and not the EP regulation. The requirements for "analysis of consequences" before tightening the regulation in Sweden, as described by the interviewee D from the authorities, can be regarded as a positive precaution to avoid requirements that make new construction too expensive but also as a preventer of more stringent regulatory requirements that could encourage innovation.

5.1.3. Comparative results

In the desk study, the stringency levels in the EP regulations in France and Sweden were presented which revealed differences in terms of quantitative requirements in kWh/m^2.year and by how much the requirements have been tightened over time. This can be related to the interview results that suggest that there are differences between the countries in terms of for example maturity of the construction sector, financial situation, and expected role of the regulation versus the market. The responses from interviewee B from the French HVAC industry association suggest that the French regulation is too stringent for the maturity level of the construction sector in the country, especially considering the economic aspects. France has set quite stringent requirements, maybe without correctly analyzing the maturity of the sector and the disadvantageous financial situation, which has contributed to a backlash and an important decrease in construction. This decrease in construction could be expected to have a negative impact on the innovative firms since there is less demand of their products. On the positive side, the French interviewees claimed that the stringent regulation has been positive for energy efficient innovative HVAC products, making more energy efficient technologies standard solutions. The impact of the stringency level of the French regulation can thus be seen as two-sided: the tight EP requirements have contributed to less construction overall which can be expected to create an unfavorable environment for innovation but they have also created a demand for more energy-efficient HVAC products since stringent regulatory requirements are difficult to reach without them.

The results of the desk study and the Swedish authority representative (interviewee D) saying that they aim at setting the minimum requirements for society indicate that the Swedish authorities do not have the same ambitious goal with the EP regulation as the French. The relatively low stringency of the Swedish regulation implies that there has been no backlash from the construction sector, but on the other hand none of the Swedish interviewees mentioned the EP regulation as having an important driving impact on innovation in the HVAC sector either. Since most requirements in the regulation are on a systems level and are not considered to be very stringent, based on the theoretic framework for this thesis, an impact of the regulation on HVAC product innovation cannot be expected. The importance of regulatory stringency for innovation is emphasized in the theoretical framework and suggests that Sweden might have missed out on energy efficient innovation that could have contributed to improving the energy performance of Swedish buildings.

5.2. Certainty

5.2.1. Results France

The French objectives achieving the nZEB objective in 2012 and creating labels for the introduction of surplus energy buildings by 2020 indicate that the authorities send out a clear signal to the industry: buildings constructed in France will need to have HVAC equipment with high energy efficiency installed. The desk study further showed that the future requirements are clearly communicated on government websites, which implies that the French regulation has high certainty.

None of the interviewees in France mentioned uncertainty concerning future EP requirements as an issue. Both interviewee A (who works for the authorities) and interviewee B (the representative from the French HVAC association) explained that actors from the construction sector were present from the early stages of the elaboration of the RT 2012 and can therefore be expected to be aware of the future requirements.

5.2.2. Results Sweden

According to the Swedish interviewees, the Swedish authorities have not yet defined the quantitative level for nZEB nor a ladder for future EP requirement levels. Two of the interviewees in Sweden mentioned the uncertainty associated with the future EP requirements of the Swedish regulation. According to the Swedish consultants (interviewees F & G) there is a lack of information concerning future regulatory EP requirements. More certainty has been demanded by the building sector. This was confirmed by interviewee D from the Swedish authorities, who stated that the construction sector wants Boverket to present future EP requirement levels. Instead of presenting the quantitative requirements for the future, the authorities have appointed investigations in order to find out what requirement levels are suitable taking into account economical consequences. Also the desk study showed that different actors in the industry have demanded clearer information on the future EP requirements. Based on the desk study results indicating that the sector wants information about future EP requirement levels and the authority representative acknowledging that they are aware of these desires, the regulatory authority in Sweden seems less willing than in France to define the future EP requirements. This implies that innovative companies in Sweden cannot rely on the EP regulation to contribute to creating a demand for energy efficient HVAC products. The effect of the regulation and the government role of "leveling the playing field" between companies as described in Dewick and Miozzo (2002) and Porter and van der Linde (1995) can therefore be expected to be minor.

5.2.3. Comparative results

Unlike the Swedish interviewees, none of the French interviewees mentioned uncertainty about future EP requirements as an issue. The French approach with setting requirements far ahead of time implies that the insecurity for innovative firms concerning whether there will be a future demand of energy efficient building components is reduced, which can be expected to have a positive impact on the innovative ambition of companies in France. At the same time, a risk with setting requirements a long time before they come into effect could be that the technological evolution may not progress as expected, and the construction sector may not be ready to live up to the requirements once they come into effect. If the perception of the future requirements is that they make construction too costly this could possibly have a negative impact on firms' competitiveness and their willingness to invest in energy-efficient innovation.

The lack of certainty in the Swedish regulation may have discouraging effects on innovation according to the study by Ashford et al. (1985). The increased uncertainty risks making innovative companies hesitant to make the investments necessary for introducing an innovative HVAC product to the market and the sector risks missing out on eco-innovation spurred by anticipation of future regulations as described in Türpitz (2003). One of the reasons why the Swedish authorities do not give clear directions on the future requirements could be that they are obliged to carefully analyze the consequences first, and it is difficult to set future requirements before having assessed the impact of the current requirements.

5.3. Flexibility

5.3.1. Results France

The desk study showed that France has a performance-based regulation, which is supposed to allow for more freedom for innovation than a prescriptive regulation. Compliance is based on calculated values using a calculation method that has been developed for regulatory purposes. An issue with the French EP regulation from a flexibility perspective is that the regulatory calculation method is inevitably based on existing solutions and technologies with known performances. This can give them a head start over innovative concepts and potentially increases the risk of locking into existing technologies, which has a hindering impact on innovation according to Allen and Sriram (2000). The French consultant (interviewee C) stated that the French calculation method makes it possible to compare multiple combinations of different building energy systems and components with each other implying that there are different options for complying with the EP regulation.

According to the authority documents used in the desk study and the French interviewees, the French EP regulation "principle of equivalence" procedure, Titre V, makes it possible for innovations to be included in French regulatory calculations and be sold on the French market. The Titre V provides the companies in the sector with more flexibility in terms of what HVAC solutions can be used in order to achieve the energy performance objectives in the French EP regulation. The difficulty with the Titre V approach according to interviewee A that works for the authorities and the consultant (interviewee C) is the balance between allowing innovative concepts to be included in the regulation and maintaining the quality of the regulation. The consultant considered that the Titre V procedure could be improved by reducing the time delay for validation of the Titre V demand, but the authority representative stated that a Titre V application needs to be carefully examined in order to maintain the quality of the regulation, which inevitably takes some time.

5.3.2. Results Sweden

Boverket publications used for the desk study showed that Sweden has a performance-based regulation. Compliance with the EP regulation is based on measured energy consumption of the finished building and there is no predefined regulatory calculation method. Interviewee D from the Swedish authorities stated that this approach is "pragmatic" and rather beneficial from an innovation perspective since there is no risk of an innovation being hindered by a calculation method to which it is not adapted. In terms of compliance method, the Swedish approach appears to be flexible since there is no predefined calculation method that has to be used to calculate the EP of a building. Interviewee E from the Swedish industrial association stated that the EP requirements are principally set on the whole building and not on specific HVAC equipment.

5.3.3. Comparative results

Both France and Sweden have performance-based regulations, where EP requirements are set on the building as a whole. According to the study by Meacham (2010), which is included in the theoretical framework of this thesis, performance-based regulations can be expected to have a positive impact on innovation by allowing for more flexibility than a prescriptive regulation. Despite having the same basic approach, signs of differences in terms of flexibility between the two regulations were identified. These differences were mainly related to the differences in compliance method: France bases compliance on calculated EP values and Sweden bases compliance on measured EP values.

Despite that a predefined EP calculation method can limit the flexibility of an EP regulation by giving an advantage to conventional solutions that are already in the calculation method, the possibility of applying for a Titre V is considered to increase the flexibility of the French regulation. The Swedish approach with allowing the use of any energy calculation software and then measuring the results of the finished building appears to be very advantageous from a flexibility perspective. It gives the actors involved in the project a lot of freedom in finding the best solution that lives up to the EP requirements and reduces the risk of locking into specific technologies. Based on the findings in the study by Johnstone et al. (2010) that is included in theoretical framework for this thesis, the high degree of flexibility in the Swedish regulation can be expected to have a positive impact on innovation.

5.4. Transparency

5.4.1. Results France

The desk study revealed a first issue with the French EP regulation that is considered to be related to transparency for the purpose of this thesis: the 1377 page long calculation method. According to a report by Bouyer (2014) that was included in the desk study, the complexity of the calculation method is presented as a potential barrier especially for more complex HVAC innovations, since it is very difficult to combine them with the complex calculation method. A second issue is that some parameters have unexpectedly large impact on the final calculated energy performance of the building according to Bouyer (2014), which may not be in accordance with confirmed building physics in some cases. As mentioned in Spiekman et al. (2010), EP calculation is not a strict science and from the point of view of innovations it is important that interest groups cannot impact the regulation, giving some products or sectors an advantage over others. The use of values from well-recognized certifications in the regulatory calculations, as is the case in France, may increase the transparency of the regulation since it should be clear under what conditions the products have been tested and that the results are reliable. On the other hand, certifications, just like regulations are based on existing products and concepts. This implies that premiering certified equipment in the regulation could favor existing products and concepts, since there may not be a certification scheme available for an innovative HVAC product or concept.

The results of the interviews in France indicated that the interviewees had differing opinions on the transparency and comprehensibility of the French EP regulation. Interviewee A, from the French authorities acknowledged that the RT 2012 calculation might appear complicated, but claimed that the consultants know how to apply the RT 2012 despite its complexity. This was confirmed by interviewee C, the French consultant. Interviewee C added that there are parts of the calculation rules that are not very clear, but that there is helpful information available. According to interviewee B from the French HVAC sector association on the other hand, the consultants enter default values instead of the true performance value of the product when the rules are not comprehensible. This means that the true energy performance of a product is not appreciated in the regulatory EP calculation, which makes it less attractive on the market. Another transparency issue involves the selection of HVAC products that are included in the French EP regulation. According to the French authority representative (interviewee A) the products that were common on the market in 2010 were included, but the HVAC sector association representative (interviewee B) stated that some products that logically should be included had been omitted for unclear reasons. Although many of these products were later inserted in the regulation, this contributes to the French regulation showing signs of incomprehensibility and unintelligibility, that based on the theoretical framework is considered to have a negative impact on innovation.

5.4.2. Results Sweden

The results of the desk study stating that the EP requirements of the Swedish regulation are based on the actual energy use of the finished building indicates a high level of transparency, since it is a compliance method that appears to be straightforward and easy to understand. According to the Swedish consultants (interviewees F & G), defining how and what energy should be measured is left to industry projects such as SVEBY. This implies less transparency of the Swedish EP regulation since it seems as though it does not make it clear what energy use should be included in the measured EP values. Like EP calculations, measuring the energy use of a building seems to be an inexact science based on the statements from the consultants and the authority representative. It is not always clear in the EP regulation what energy should be measured, how this should be done, what should be included into the EP results. There are also technical difficulties related to measuring the energy use of a building. Interviewee E, the Swedish HVAC association representative stated that the EP requirements in the Swedish EP regulation are set on a systems level, and the consultants (interviewees F & G), added that measuring the energy use of building subcomponents has more to do with demands from clients than regulatory requirements. Therefore, the regulatory requirements on specific HVAC components in the Swedish EP regulation could be described as somewhat unclear which according to the theoretical framework implies little incentive for energy efficient innovation in HVAC products.

5.4.3. Comparative results

The results of this thesis work concerning the transparency of the French EP regulation were discordant, with all interviewees acknowledging that it was complex but according to the French consultant (interviewee C) and the authority representative (interviewee A) professionals knew how to apply it well. According to the French HVAC industry representative (interviewee B) though, the complexity of the calculation method can lead to conventional solutions being given an advantage over innovations. Another possible consequence of the complexity of the regulation is mentioned in the study by Bouyer (2014): it can become a barrier to the innovation of more complex and sophisticated HVAC products. The innovative firms know it will be very difficult (if not impossible) to validate a Titre V for a complex innovation, which means it cannot be sold on the French market.

Where the challenges related to transparency with the French regulation relate mainly to the complex calculation method that attempts to describe the building in a detailed manner, the Sweden transparency challenges are rather related to not defining what energy should be included in the EP value and how it should be measured. The Swedish approach with measuring the actual energy used appears to be very transparent, but the interview results revealed some incoherencies related to how and what energy should be measured. The perceived lack of definition and guidance could be seen as reducing the transparency of the Swedish regulatory scheme by making it too general, which based on the findings by Rothwell (1992) that is included in the theoretic framework, is suggested to have a negative impact on HVAC innovation.

5.5. Enforcement

5.5.1. Results France

According to the desk study France has reinforced the controls of compliance with the RT 2012, with hopes that the high workaround rate from the RT 2005 will be reduced according to Bataille and Birraux (2009). The results of the interviews showed that the penalties for non-compliance have also been increased with the RT 2012. Interviewee A, that works for the French authorities stated that a very low percentage of new buildings are checked every year. Despite this, according to the French consultant (interviewee C) there has already been a prosecution due to non-compliance with the EP regulation. The penalties for non-compliance with the EP regulation in France are quite high and include possible prison penalty up to 6 months.

5.5.2. Results Sweden

According to interviewee D from the Swedish authorities, the EP regulation is set on a national level but the responsibility of enforcement lies on the local authorities. The desk study for this thesis presented the results of a project finding that almost 60% of buildings constructed between 2007 and 2012 do not live up to the requirements of the Swedish EP regulation. This can be considered to indicate that the enforcement of the regulation may not be strict enough to have a driving effect on innovation as described in Ashford et al. (1985).

In Sweden, interviewee D mentioned enforcement as the weak link of the regulatory system. Boverket is working at enforcing the controls in cooperation with local authorities by giving them access to the directory of energy declarations. In terms of penalties for non-compliance, one of the consultants mentioned that theoretically there are sanctions but did not know of any cases where they had been enforced.

5.5.3. Comparative results

The French EP calculations with a large number of inputs and outputs can be expected to be difficult and time-consuming to verify, and the authorities only have the funds to check a very small percentage of the new buildings every year. On the other hand, the increased penalties for non-compliance can be expected to increase compliance with the building rules and therefore have a positive impact on innovation based on the theoretical framework for this thesis.

Through the interviews and desk study, a risk that the enforcement of the EP regulations falls between jurisdictions was identified: Boverket is the authority responsible for the EP regulation but the responsibility of verification is on the municipalities. Interviewee D, from the Swedish authorities stated that there is progress in the making though, with the EP declaration register being available to the municipalities. This evolution can be expected to have a positive impact on innovation from an enforcement standpoint. The Swedish EP regulation shows signs of a lack of consequences for non-compliance with the EP requirements. Based on the theoretical framework for this thesis, more efficient enforcement of the EP regulation can be expected to have a positive impact on innovation.

Table 3. Summary of analysis of the impact of EP regulations in France and Sweden on HVAC innovation

Characteristic:	France	Sweden
Stringency	High level of stringency; contributed to energy efficient HVAC equipment becoming standard but also to making construction too costly. High ambitions.	Relatively low level of stringency, stricter EP requirements demanded by the construction sector.
Certainty	Requirements for 2020 already defined, sends out clear signal to innovative firms.	Information about future EP requirements are demanded by the construction sector, but has not been published by the authorities.
Flexibility	Defined regulatory calculation method is inevitably based on existing products. Possible to include innovations via Titre V procedure.	No defined calculation method, approach with measuring energy use of finished building considered to be flexible.
Transparency	1377 pages of calculation method is difficult to oversee, and not always concordant with conventional building physics.	The Swedish approach is straightforward and coherent, but it is not defined what energy use should be included in the measurement results.
Enforcement	Low percentage of new buildings is controlled every year, and the complexity of the calculation method makes it difficult to verify. High penalties.	Risk that control of compliance falls between jurisdictions. No known cases of penalties.

6. Conclusions and discussion

In this chapter, the answer to the main research question is presented and the questions that guided the literature study are answered in a summarized fashion. For a more exhaustive answer to these questions, refer to section 3.3-3.5. The methods used for the thesis work are also discussed and the conclusions of the thesis are discussed in terms of implications for innovative firms, legislative authorities and suggestions for further research.

6.1. Overview

The point of departure for this thesis is the ambition of the European Union (EU) to fulfilling their environmental commitments by reducing the energy consumption of buildings. One way of doing so is by taking actions aimed at improving the energy performance of the buildings in the European member states. This is why the EU has adopted the Energy Performance of Buildings Directive (EPBD) that obliges the member states to set quantitative limits for the energy performance of buildings as well as define a methodology for how the energy performance of buildings should be calculated. However, as a directive the EPBD leaves it up to every member state to design their EP regulation. The differences in for example climate and building tradition are contributing reasons to why the EP regulations differ between the European member states. Regulations are a way for government to steer development in a desirable direction, but at the same time regulations might give an advantage to existing technologies and become an obstacle for innovation. Improving the energy performance of buildings can be done with existing technology, but it is also possible that new innovations can result in a better energy performance at a lower cost. Since the HVAC installations consume half of the energy in buildings in the developed world it can be considered an important sector from a building energy perspective. The overall purpose of this thesis is to contribute to a better understanding of the impact of EP regulations on innovation in the HVAC sector. A more specific aim is to compare and contrast EP regulations in two EU member states and discuss the expected impact of the regulations on innovation based on specific regulation design characteristics.

6.2. Answers to research questions

- *How can regulation impact innovation?*

Regulations can be seen as the authorities tool to push the market in a desired direction (Pelkmans & Renda, 2014). The review of literature in the theoretical framework revealed that the relationship between regulation and innovation is quite complex. Innovation in itself can be affected by many different factors, of which regulation is just one. Regulations can encourage, hinder or just impact the direction of innovation, strongly depending on how the regulation is designed. According to the literature in the theoretical framework for this thesis, regulations can be said to promote innovation by defining requirements on performance and quality, setting a foundation that innovation can stand on. Environmental regulations, if properly designed, were found to encourage innovation by leveling the playing field and obliging all firms to develop innovations that reach the environmental objectives of the regulation. Regulations can create an "artificial" demand for innovative technologies and decrease the uncertainty of the future demand of the innovation, making firms less hesitant to invest in innovative activities. In the studies of the theoretical framework, regulations were found to discourage innovation by giving advantage to existing solutions, being unclear or unrealistic, being non-predictable and not providing certainty about future requirement levels.

In the case of EP regulations and HVAC innovation, it seems as though the objective should be to design a regulation that can make the manufacturers of HVAC products willing to invest in research and development of products that contribute to buildings with good energy performance. For the innovative firms this is a question of investment in relation to possible profit and energy efficiency of the product. One problem related to EP regulation and HVAC innovation is how to assess the energy performance of a building and how to judge what HVAC product is better than another from an energy efficiency perspective. In the current situation there are no perfectly reliable calculation methods and Spiekman et al. (2010) declare that it is difficult to calculate the true energy consumption of a building. Many options have been discussed, and as this thesis shows the European member states have chosen different ways of defining the energy performance of a building. At the same time, Wouters et al. (2004) argue that the industry is looking more and more at the EP regulations in the innovation process, in order to make sure that the innovation is compatible with the regulation. As EP regulations are on a national level it is likely to believe that also the EPBD is important, as it is the gate to a bigger market in the EU. So, it seems necessary that future revisions of the EPBD be made with innovation in mind in order to increase the probability of the national EP regulations having a positive impact on innovation. It is important how directives and regulations are designed in order to avoid that the EP regulation becomes a barrier to for example innovations that are not included in a calculation method (Wouters et al., 2004) or that it is impacted by lobbyists (Spiekman et al. 2010).

- *What characteristics of regulation design have an impact on innovation?*

According to the theoretical framework of this thesis, regulation design characteristics are important for the impact of a regulation on innovation. Five specific regulation design characteristics were identified in the literature review and included in the analysis model. The five characteristics are stringency, certainty, flexibility, transparency and enforcement. Other characteristics than these five were found but not included in the analysis model, either because they were not explicitly defined in the literature, not applicable to the case of EP regulations and HVAC innovation or because there was not enough support for their relevance in the literature of the theoretical framework.

The first characteristic of the analysis model is stringency. According to many of the studies in the theoretical framework (see p. 25 for an overview of references), a more stringent regulation may force the firms to innovate whereas no or little innovative activity can be expected with a lax regulation. A too stringent regulation though can have a discouraging impact on innovation. In the reviewed studies, certainty about future regulatory requirements was also considered to be important for the impact of a regulation on innovation. Regulatory certainty is suggested to make firms more willing to innovate since they can expect the regulation to contribute to ensuring a future demand of the innovation thus reducing the risk involved with innovation. The third regulatory characteristic in the analysis model is flexibility; whether the regulation allows for innovative firms to find the best solution and does not lock in to conventional or existing technologies and solutions. In the literature reviewed, a regulation was difficult to oversee, not clearly based on scientific principles or affected by different interest groups could be expected to have a more negative impact on innovation. In the analysis model this was referred to as transparency. The last regulatory characteristic emphasized by the literature in the theoretical framework for its impact on innovation is enforcement. When enforcement of the regulation is weak, the regulation can be expected to have little encouraging impact on the firms' willingness to innovate.

- *How can the design of the French and Swedish energy building regulations be expected to impact innovation in the HVAC field?*

A conclusion of the analysis of the Swedish EP regulation is that it shows signs of low stringency, lack of certainty about future requirements and weak enforcement, which according to the theoretical framework indicates that the regulation should not be expected to be a driver to innovation. Increasing the stringency by setting stricter energy performance requirements in the EP regulation could incite an increase in energy efficient HVAC innovation, since all building subsystems would have to be more energy efficient to live up to the requirements. A decision from Boverket about the future demands on energy performance requirements could strengthen the certainty of the Swedish EP regulation and make innovative firms more willing to invest in energy efficient HVAC innovation. Higher stringency, certainty and stronger enforcement could be expected to ensure the demand of energy efficient HVAC equipment and thereby incite innovation. On the other hand, the results of the analysis suggest that the Swedish EP regulation has a high level of flexibility, implying that any innovation can be used as long as the finished building lives up to the energy performance and functional requirements of the regulation. This flexibility leaves a lot of freedom for innovations to be accepted and successful on the Swedish market. Furthermore, the analysis indicated that the approach with measuring the actual energy performance of the finished building is transparent and comprehensible in theory, which is considered to be positive for innovation. However, the interviews with Swedish consultants (interviewees F & G) suggest that measuring the energy use of buildings is not so easy and straightforward in practice. Summing up, from the results of this thesis one can not state that the Swedish EP regulation drives or hinders HVAC innovation. There seems to be both advantages and disadvantages with the Swedish EP regulation in terms of the impact on innovation, depending on which characteristics are considered.

The results of the desk study and the interviews showed that the French energy performance regulation approach differs quite dramatically from the Swedish. Where the Swedish regulatory scheme has no predefined EP calculation method, the French method was described by the French interviewees as being meticulously detailed and attempting to describe the building in an as detailed manner as possible. The analysis indicated that the French EP regulation has a high level of stringency and certainty as the very ambitious EP requirements for 2020 have already been presented. These are regulation design characteristics that are considered to have a positive impact on innovation according to the analysis model. The regulatory EP calculation method is inevitably based on existing products and solutions, potentially giving them an advantage over innovations. Based on the analysis, this regulatory approach implies lower flexibility, which according to the analysis model is negative for innovation. To deal with this, the French regulatory system includes a procedure for implementing innovations in the regulatory calculation method, Titre V. This can be expected to make the regulation more flexible by allowing new products an opportunity to be included in the regulation. At the same time, the procedure takes time and costs money, which is an additional expense for an innovating firm in France in addition to the costs associated with developing and introducing a new product to the market. Concerning the transparency of the French regulation, the results of the desk study and interviews for this thesis are discordant. On one hand, the answers from interviewee from the French HVAC industry association (interviewee B) and a report by Bouyer (2014) suggest that the complex calculation method is hard to combine with complex HVAC innovations. They further conclude that the complexity contributes to the French market locking in to conventional solutions and puts innovative solutions at a disadvantage. On the other hand, the interviewee from the French authorities (interviewee A) and the French consultant (interviewee C) claimed that the consultants knew the regulation so well by now that its complexity was not an issue. The complexity of the regulatory calculation method can be expected to make enforcement a tedious task. Few new buildings are checked for compliance due to the authorities' limited resources. However, the desk study showed that the penalties for non-compliance were quite high and the French consultant (interviewee C) stated that there had been court cases due to failure of compliance with the EP regulation. This can be expected to elevate the rate of compliance, thereby implying a positive impact on innovation according to the analysis model. The results of the interviews in France indicate that the French EP regulation can, and has, acted as a driver towards more energy efficient HVAC products. Based on the analysis model this is considered to be thanks to the high stringency and certainty about future requirements. At the same time the EP regulation was also perceived as a potential barrier to innovation, which was especially emphasized in a report included in the desk study. The regulation design characteristics that contributed to the negative impact on innovation are considered to be the signs of low flexibility of the EP calculation method approach and low transparency of the complex calculation method. A conclusion from this thesis is that the risk of the French EP regulation becoming a barrier to innovation can be expected to be larger for more complex or groundbreaking HVAC innovations. It can be difficult to find a way to assess their performance within the boundaries of the complex EP calculation method.

In addition, the design of the two regulations seems to reflect the ambitions of the authorities. In France, the ambition is to be a forerunner in terms of EP policy whereas according to the interviewee from the Swedish authorities (interviewee D) their ambition is to set the minimum EP requirements and leave it up to the market and construction sector to push the evolution towards more energy efficient buildings. The liberal Swedish regulatory approach could be a contributing reason to why there are a lot of collaboration projects within the construction sector, such as the SVEBY project concerning standardization and verification of the energy performance of buildings or Svensk Ventilation's guidelines for how to present performance values for HVAC equipment. It could also be the other way around: that it is possible to have a liberal EP regulation in Sweden because the construction sector takes responsibility of subjects that are handled by the EP regulation in other EU member states.

6.3. Reflecting on implications for legislating authorities

The knowledge gained within the scope of this thesis work indicates that there are advantages and disadvantages with both the French and the Swedish EP regulation in terms of their impact on innovation. The French EP regulation with a detailed calculation method showed signs of being advantageous from a stringency, certainty and enforcement perspective. The Swedish EP regulation, where compliance is based on measured EP of a finished building seemed to be flexible and transparent but less stringent and more uncertain in terms of future requirements. Since the results of this thesis suggest that the differences in design between the EP regulations in France and Sweden are important for how the regulations impact on innovation, a recommendation to legislating authorities in European member states is to study how other countries have set up their regulation scheme and learn from each other. The EP regulations are to be reviewed with regular intervals, which provides an opportunity for the legislating authorities to evaluate and revise the regulation. Since innovation can contribute to the main objective of the EP regulations, the results of this thesis indicate that the impact on innovation is an aspect that should be taken into account in the revision process. This seems to be particularly important in countries such as France where the regulation scheme shows signs of being more rigid, where the conclusions of this thesis suggest that the risk of the EP regulation becoming a barrier to innovation is more imminent than in countries considered to have a more flexible EP regulation scheme such as Sweden.

The results of this thesis work suggest that using a predefined energy performance calculation method for proving the compliance with the EP requirements can be problematic from an innovation standpoint. Primarily, the use of a calculation method was found in the analysis to lower the flexibility of the regulation, which allows for less freedom for innovative firms. If the calculation method is very complex or difficult to comprehend, it is also considered to lower the transparency of the regulation. Even though the French EP calculation method provides an opportunity for including innovations (Titre V procedure), according to the analysis existing solutions can still be considered to have an advantage over innovation. The Titre V procedure takes time and costs money, in addition to the conventional costs associated with introducing an innovation to the market. The other disadvantage with the calculation method approach is related to the innovation-regulation paradox described in Dewick and Miozzo (2002). A calculation method is based on existing HVAC products and solutions, which means that it may not allow for the full functionality of an HVAC innovation to be assessed in the calculation. This potentially results in a worse energy performance for the building as a whole than if a conventional HVAC solution was used. The results of the analysis suggest that the Swedish general approach with measuring the energy use of the final building instead of having a predefined calculation method decreases the risk of the regulation becoming a barrier to innovative HVAC products and solutions. Although the interviewees' perception of how the calculation method of the French EP regulation impacted on innovation was discordant, the results of this thesis work suggest that transitioning from compliance being based on calculated values to measured values of the finished building could have a positive impact on innovation. As indicated by the Swedish consultants, measuring energy use of a finished building is not as easy as it sounds and it seems as though there is work to be done in terms of increasing the competency and knowledge concerning what energy should be measured or how. For the impact on innovation, a conclusion of this thesis is that the basic concept of measuring energy instead of calculating it seems to be more advantageous. Therefore a suggestion is to consecrate resources towards ameliorating the processes related to measuring the energy use of buildings instead of developing a more complex EP calculation method.

6.4. Reflecting on implications for innovative firms

To introduce new products to the market is essential for the success of a firm (Fahy & Jobber, 2012), but innovation costs money and that cost has to be compared with the expected financial outcomes of the innovation. This thesis indicates that the risks associated with developing HVAC innovations with high energy efficiency can be reduced if the EP regulations are properly designed. Both the reduction of energy consumed by buildings and innovation are considered important for the EU, and EU projects exploring the impact of EP regulations on innovation have taken place. This thesis has shown that there is still a lot of work to be done in the field, which means that innovative firms may be faced with EP regulations that are a barrier to innovation. The analysis of the French and Swedish EP regulations pointed at differences in the regulation design that affect their impact on innovation. Since regulations are a factor that has to be taken into account in the innovation process, it is considered important for the firms to have knowledge about how the EP regulation is designed. This would allow the firm to better cope with the eventual barrier to innovation caused by the EP regulation, or even better, use the regulation to their advantage if possible.

The characteristics of regulation design included in the proposed analysis model could be a tool for firms to use when trying to evaluate the expected impact of the EP regulation in a country on innovation. It would be useful for an innovative HVAC firm to asses the stringency level of an EP regulation in order to know what energy efficiency their products need to have in order to live up to the regulatory EP requirements in a cost-efficient way. Knowledge about the certainty of the EP regulation and the signals from the authorities about future EP requirements relates to whether the firm can expect the EP regulation to play a role in creating a demand for HVAC products that contribute to more energy efficient buildings. Since the innovative firms are expected to present the market with HVAC products that live up to regulatory requirements, awareness of the transparency of an EP regulation could be useful in the innovation process. If the regulation has low transparency, i.e. it is perceived as biased by different interest groups, not based on scientific principles, incomprehensible or unclear the innovative firm can probably expect to have to spend more time and money on procedures related to ensuring that the innovation is adapted to the regulation.

The results of this thesis work have another dimension for international HVAC companies that aim at introducing their products on a market in a country other than the one where it was developed. Most innovative firms are probably somewhat aware of the regulation of the country where the product is developed. They risk having to spend time and money on different procedures when trying to introduce the product to a market abroad, depending on the design of the EP regulation in that particular country. Based on the conclusions of this thesis, the design of the EP regulation should be a factor taken into account when deciding about market introductions abroad in order to avoid spending time and money in vain. Knowing whether the general energy performance regulation approach is relatively liberal or more detailed and rigid is useful. In case the regulation is more rigid, the results of this thesis suggest that it is a good idea for the firm to assess whether their innovation is adapted to the energy performance regulation in place. If this is not the case, the firm will most likely need to spend time and money on equivalence procedures such as the Titre V in France. An EP regulation that shows signs of having relatively low stringency levels and lacking in certainty about future EP requirements, as in Sweden, can present other challenges for innovative firms. It seems as though being well familiarized with the market and construction sector in the country becomes more important than in countries where a more rigid EP regulation is in place. Based on the reasoning of for example Porter and van der Linde (1995), a stringent regulation where the future requirements have already been defined is suggested to be able to contribute to a future demand of energy efficient HVAC products and solutions.

6.5. Method discussion

The work for this thesis has been performed in two different countries and three different languages (French, Swedish and English). Despite the researcher's proficiency in all languages, there is a risk of misunderstandings and opinions and experiences being lost in translation. That is why it has been important to reconnect with the interviewees and make sure that the researcher has correctly interpreted what they said in the interviews. A second issue is related to the legislative and juridical differences between the EP regulations in France and Sweden. As mentioned in section 1.4. these differences are not taken into account in this thesis. The differences include what authority is responsible for the EP regulation and what power they have, which means that the authority representatives included in the interview study were not perfectly analogous. Despite this, the interviewees were still considered to have the unique experience and the knowledge necessary to contribute to the purpose of this thesis.

The purpose of this thesis is to contribute to a better understanding of the EP regulations on HVAC innovation. To make generalizations regarding the findings presented in this thesis, additional countries and respondents need to be addressed. Moreover, one delimitation of this thesis work was focusing on the impact of the design of EP regulations on innovation and practically ignoring how successful the regulation was in reaching its primary objective: reducing the energy consumed by buildings. Whether the design of the EP regulations contribute to better energy performance of buildings in the EU or not is a very relevant subject, but due to the limited time for this thesis work it was not included.

Besides increasing the understanding of the impact of EP regulations on HVAC innovation, this thesis also proposes a model for analyzing EP regulations in terms of their expected impact on innovation in the HVAC sector. The analysis model facilitated the comparison between EP regulations in France and Sweden in an analytical way. It also became the link between existing literature on the impact of regulation on innovation and the knowledge about the impact of EP regulations on innovation in the HVAC sector provided by this thesis. For this thesis the analysis model fulfilled its purpose of providing a meaningful way of assessing and comparing the EP regulations in France and Sweden. The results of the interviews suggested that there are differences between the two member states studied for this thesis in terms of climate, economic situation, building tradition and maturity of the construction sector. These factors are outside the scope of this thesis work, but could still be expected to have an impact on innovation based on the innovation system approach described in Kemp et al. (2002) and presented in section 3.3. of this report. A larger study could potentially include more of the factors included in an innovation system, extending the analysis model and studying EP regulations in more countries.

The EU projects studied within the scope of this thesis work (see section 3.2.) indicated that SIMILAR TO FRANCE most European member states besides Sweden have chosen to develop a calculation method for the energy performance of buildings, and base compliance with the EP regulation on calculated values. Including Sweden in the thesis therefore turned out to be an interesting choice.

6.6. Suggestions for further research

This thesis provides only a glimpse of the challenges related to HVAC innovation and energy performance regulations. Suggestions for further research include extending the study to more member states, doing case studies on real HVAC innovations and how they are impacted by regulations and doing an extensive quantitative study including more actors from the construction sector. Further studies using the analysis model developed for this thesis including more countries would also be interesting, in order to develop a systematic overview of the EP regulations in different EU member states and how they can be expected to impact innovation. As mentioned in the previous section, further research could also include evaluating the analysis model with the objective of making it useful for drawing conclusions on the impact of EP regulations throughout the EU and their expected impact on innovation.

The EU financed projects studying the impact of the EP regulations on innovation seem to have assumed that all member states have developed a regulatory calculation method, which Sweden has not. Another suggestion for future research is an assessment of the impact on innovation between having a regulatory EP calculation method and measuring energy use of the finished building.

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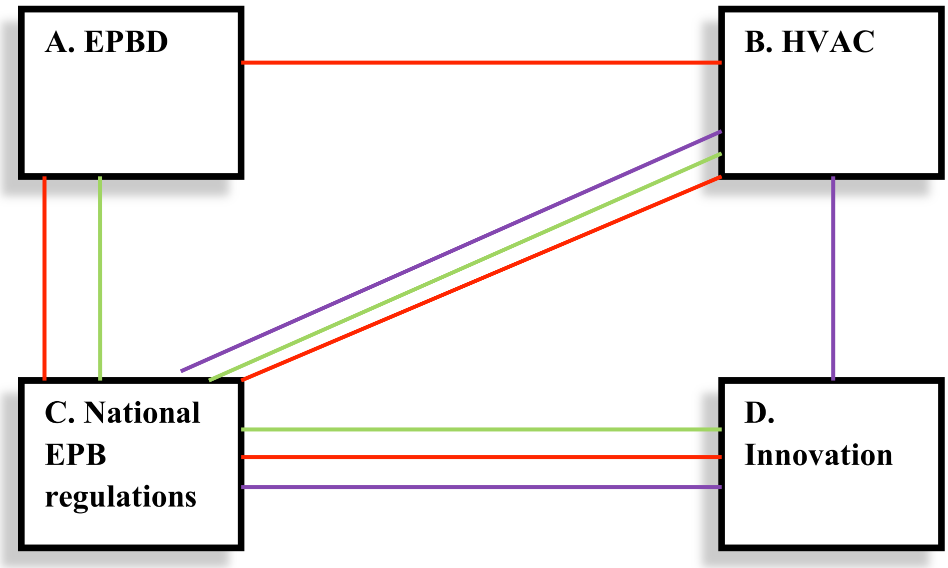
Appendix I. Interview guide

Interview guide

« Energy Performance of Buildings regulations in Sweden and France and their impact on HVAC innovation »



Legend:

= participant in elaboration of EPB regulation

= industrial association

= person with experience of applying the regulation

- 4 areas of interest
- The different actors have different points of view and knowledge on the subject
- Therefore; the interview questions will differ between the actors in order to get a fuller comprehension of the subject from multiple points of view.

Interview with actor 1: Participant in elaboration of EPB regulation

AC: EPBD and the national EPB regulation

-What is your role in the elaboration of the national EPB regulation?

-How do you see the future influence of the EPBD on national EPB regulation, in terms of harmonization of EP requirements and calculation methods?

1. How was the detail and complexity level of the regulation selected? What factors affected the choice? Advantages and disadvantages with the chosen approach?
2. What is your professional view on the future evolution of the detail and complexity level of the EPB regulation? (Do you think it will it become more or less detailed? In terms of calculation method? What will become more or less detailed? What do you think about this evolution?)
3. Who can perform a regulatory calculation? (i.e. professional or amateur?) Are there any advantages/disadvantages with this?

BC: National EPB regulations and HVAC

-Considering that regulations require buildings to become more airtight, how does this affect the significance given to ventilation in the regulation? How does this affect the performance requirement of the ventilation system?

4. What is compliance with the EPB regulation based on? (Calculations or actual measuring of energy consumption of the building? What are the advantages and disadvantages of this approach?)
5. How is compliance with the EPB regulation controlled and enforced? (who is responsible?)
6. How have the products and solutions included in the calculation method been selected?

CD: Innovations in the national EPB regulation

7. How are innovations taken into account in regulatory calculations in your country and what are the advantages and disadvantages of this approach in your professional opinion?
8. Has the integration of innovations in regulatory calculations changed over time (i.e. with new versions of the regulation), and if so, how?
9. With respect to question 1, how does the chosen detail/complexity level affect HVAC innovation in your professional opinion?

Interview with actor 2: Industrial association (Uniclima/Svensk ventilation)

AB: EPBD and the HVAC sector

1. Has the EPBD impacted your sector, and if so, how? (in terms of EPBD regarding the buildings as a whole, unlike the eco-design directive dealing with the products)
2. Do you collaborate with corresponding organizations internationally on EPBD-related issues, and if so, how?

AC: EPBD and the national EPB regulation

3. To what extent has your organization participated in the elaboration of the national EPB regulation? (On a scale, from 1 -10? What was the most important input? Who asked for it?)
4. How have you and/or the companies you represent been affected by the national EPB regulation (in a positive/negative way)?
5. With respect to the previous question, have any specific actions been taken, and if so, which do you consider the most important?

BC: National EPB regulations and HVAC

6. In your professional opinion, how has the national EPB regulation in place affected the HVAC sector in your country?
7. How would you, as a representative for Uniclima/Svensk Ventilation, describe the significance of HVAC systems in the national EPB regulation? (i.e. compared to isolation, windows, energy supply systems, regulation, lighting etc… where does it fall?)

CD: Innovations in the national EPB regulation

8. How does the method of integration of HVAC innovations in the regulatory calculations affect you and/or the companies you represent?

Interview with actor 3: Person having worked with applications of the RT 2012

BC: National EPB regulations and HVAC

1. How would you describe the national EPB regulation in your country?
2. According to your professional opinion, is the national EPB regulation an efficient way of reducing the energy consumption of buildings and if so, how?
3. How is compliance with the EPB regulation controlled and enforced?
4. According to you professional experience, has the national EPB regulation in your country had an impact on the HVAC sector and if so, how? (Energy efficiency? Has it led to dramatic evolution? Technical development?)
5. What is your professional opinion on how the performance and characteristics of HVAC equipment is valorized in the EPB regulation in your country? (Is it detailed enough/not too detailed? Are relevant characteristics taken into account and are they valued correctly? Close to reality?)

BD: HVAC and innovation

6. How has the HVAC sector in your country evolved the last ten years in terms of energy-efficient innovations? (Completely new products/solutions or improvement of existing products/solutions? Linked to EPBD?)

CD: Innovations in the national EPB regulation

7. Can the EPB regulation in your country impact HVAC innovations, and if so, how? (barrier/driver)
8. What do you consider the main advantages/disadvantages with the approach to integration of innovations in the EPB regulation in your country? (How could the regulation be reformed to be more of a driver to innovation?)