Building Sustainability

Studies on incentives in construction and management of real estate

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Doctoral Thesis

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Abstract

This thesis summarizes the results from several studies with connection to sustainability in construction and management of real estate. Here, the concept sustainability includes environmental, social and economic dimensions and focus is on the actors with the best possibilities to impact real estate, namely the real estate owners and the developers. The thesis consists of six papers. Real estate owners' perception of and incentives and strategies for sustainability was studied in four ways: incentives for energy efficiency and other sustainability issues in connection to renovation (papers I and II), factors that characterize firms with an ambitious approach to energy efficiency (paper V) and economic incentives for energy efficiency (paper VI). Developers' behavior and impact on sustainability was studied in two ways: how developers' planning and construction methods may influence energy consumption for future residents (paper III) and how developers relate to requirements for building environmental certification levels (paper IV).

The first paper aims to clarify how housing firms see and treat energy efficiency matters in connection to renovation of multi-family buildings constructed during the 1960's and 70's. Interviews with housing firms resulted in four ideal housing firm types illustrating that housing firms have more or less incentives to improve energy efficiency. The second paper aimed to study a model for renovation of buildings in a residential area in peripheral Stockholm and to assess how it considers environmental, social and economic sustainability as well as technical concerns.

Paper V builds on the results in paper I and aims to identify factors, on a firm level as well as in the surroundings of the firm, that characterize housing firms who own multi-family buildings from the 1960's and 70's and who have an ambitious approach to energy efficiency.

Paper VI uses information from energy performance certificates to study whether better energy performance increases the selling price of single-family homes, which would increase owners' incentives to improve energy efficiency.

Paper III takes its starting point in an indicated shift in developers' planning and construction practices for laundry facilities in owner-occupied multi-family buildings. The paper aims to clarify whether a shift has actually occurred from communal laundry rooms to in-unit laundry appliances and to illuminate the impact this could have on residents' energy consumption for laundry. Paper IV reports the study of how developers who have adopted the environmental certification system LEED relate to the requirements for specific certification levels and how updated requirements risk undermining developers' incentives for sustainable construction.

Keywords: sustainability, sustainable buildings, sustainable renovation, sustainable construction, sustainable management, housing, sustainable building certification, energy efficiency, incentives.

Sammanfattning

Den här avhandlingen sammanfattar arbetet från flera studier med koppling till hållbarhet inom bygg och förvaltning av fastigheter. Begreppet hållbarhet omfattar här tre dimensioner: miljömässig, social och ekonomisk hållbarhet, och fokus ligger på de aktörer som har mest möjlighet att påverka fastigheterna, nämligen fastighetsägare och projektutvecklare. I avhandlingen ingår sex uppsatser. Fastighetsägares uppfattning av och incitament och strategier för hållbarhet undersöktes på fyra olika sätt: incitament för energieffektivisering och andra hållbarhetsfrågor i samband med renovering (uppsats I och II), faktorer som karaktäriserar företag med ett ambitiöst förhållningssätt i energieffektiviseringsfrågor (uppsats V) samt ekonomiska incitament för energieffektivisering (uppsats VI). Projektutvecklares beteende och påverkan på hållbarhet undersöktes på två sätt: hur projektutvecklares planering och byggmetoder kan påverka energianvändningen för framtida boende (uppsats III) och hur projektutvecklare förhåller sig till kravnivåer i miljöcertifiering av byggnader (uppsats IV).

Den första uppsatsen syftar till att belysa hur bostadsföretag ser på och behandlar energieffektiviseringsfrågor i samband med renovering av flerbostadshus byggda under miljonprogrammet. Baserat på intervjuer med bostadsföretag resulterade den explorativa studien i konstruktionen av fyra idealtyper av bostadsföretag med mer eller mindre incitament för att energieffektivisera. Den andra uppsatsen syftade till att undersöka en modell för renovering av miljonprogramshus i ett bostadsområde i Stockholms ytterområden och bedöma hur den tar hänsyn till miljömässig, social och ekonomisk hållbarhet tillsammans med tekniska överväganden.

Uppsats V bygger på resultaten i uppsats I och syftar till att urskilja faktorer, såväl på företagsnivå som i företagets omgivning, som karaktäriserar bostadsföretag som äger flerbostadshus från miljonprogramsåren och som har en ambitiös hållning i energieffektiviseringsfrågor.

Uppsats VI använder information från energideklarationer för att undersöka om bättre energiprestanda ökar försäljningspriset på småhus, något som skulle öka ägarens incitament för energieffektivisering.

Uppsats III utgår från en indikerad förändring i projektutvecklares planering och byggmetoder av tvättinrättningar i flerbostadshus med bostadsrätt. Uppsatsen syftar till att klarlägga om en förändring har skett från gemensam tvättstuga till tvättmöjligheter i den egna bostaden och belysa vilken effekt det skulle kunna ha på de boendes energianvändning för tvätt. I uppsats IV klarläggs hur projektutvecklare som bygger enligt miljöcertifieringssystemet LEED förhåller sig till kraven för att uppnå nivåerna för att klassificeras och hur uppdaterade kravnivåer riskerar att undergräva projektutvecklarnas incitament för att bygga hållbart.

Nyckelord: hållbara byggnader, hållbar renovering, hållbart byggande, hållbar förvaltning, bostäder, miljöcertifiering, energieffektivisering, incitament.

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Lovisa Högberg

Contents

1 INTRODUCTION

In 2008, the Swedish government commissioned a delegation for sustainable cities; to promote a sustainable development in urban, conurban and residential areas. The focus was to create well-functioning and attractive urban environments where high quality of life goes hand in hand with an improved environment, social cohesion and minimized climate impact (Dir. 2011:29). The commission was but one of many national and local initiatives that have arisen over the past decades as a response to ecologically, socially and economically unsustainable built environment (see, for example, Sustainable cities, 2014).

If the needs of both our generation and future generations are to be met, the current use and impact of real estate is not possible to sustain. According to the WWF, 70 % of the world's population live in urban areas, mankind's ecological footprint exceeds the capacity of the planet by 50 % and ecosystem services and biodiversity are currently being seriously compromised (WWF, 2013). The United Nations Environmental Programme reports that globally, the built environment is responsible for 40 % of global energy use, 30 % of greenhouse gas emissions, 20 % of water usage and annually uses 3 billion tonnes of raw materials (UNEP, 2014). In Sweden, the building sector accounts for almost 30 % of total energy consumption, 20 % of greenhouse gas emissions and in 2007, waste from the building and amenity sector in Sweden amounted to 32 million tonnes, corresponding to 27 % of total waste (Toller *et al.*, 2009).

In addition to the built environment's excessive ecological footprint, socio-economic segregation is growing, sometimes resulting in an increased social unrest, also across Sweden (Lilja & Perner, 2010; Malmberg *et al.*, 2013). A number of particularly disadvantaged Swedish areas were targeted with national social investments, in spite of which only little improvement has been shown in socio-economic indicators with regards to unemployment and welfare dependency, and despite of which stagnation or degradation has been observed with regards to school performance, youth unemployment, social insecurity and instability (Ministry of Employment, 2013). Unattractive areas, plagued by explicit unrest or simply experiencing depopulation, risk ending up in a negative spiral of unemployment, welfare dependency and crime (Nilsson & Lundmark, 2012).

In socio-economically run-down areas, it is also more difficult to motivate the business case for investments in real estate. Failing to do so, however, may result in further reinforcement of the built environment's negative impact on our ecosystems and on residents' health and well-being. Given that socio-economic decline and distress often geographically coincides with the large portion of post-war buildings in need of renovation, this is a particularly challenging problem in Sweden and in many European countries today (Carpenter, 2006; Blomé, 2011).

As a contrast to this, it is tempting to envision a system of buildings and infrastructure that in its use doesn't parasitize on future generations' resources by preying on surrounding ecosystems, by compromising the health and wellbeing of the people who live in it or by excessively indebting people, firms or the public sector. Construction and management of real estate will play a key role in this. The question is what incentives there are for sustainable construction and management and if lacking, how they can be provided to help realize this vision.

Undeniably, to reach a state of sustainability constitutes a great challenge. The resource use in construction and management of buildings; the impact of buildings on ecosystems and biodiversity; socio-economic segregation along with economic challenges tied to real estate are all examples of how the built environment is interrelated ecologically, socially and economically. Efforts to achieve a sustainable built environment need to address all of these dimensions; however, there are conflicts of interests involved when trying to avoid compromising one or more of the dimensions.

This thesis addresses the environmental, economic and social sustainability dimensions of real estate. The excessive ecological footprint, the social damage and costs implied by the current economy as described here indicate that real estate is not sustainable. In addition to weighing current and future consumption against each other, the three dimensions need to be balanced. What degree of compromise between conflicting objectives that can be deemed acceptable will ultimately be a policy issue, but a minimal requirement is to give them all consideration.

The complexity of the built environment calls for a holistic approach, in which challenges are identified on different levels in a larger system, and in which all types of actors participate to meet these challenges. At the core of realization are the actors who have the direct possibility to influence the built environment in a positive direction. Real estate owners are one particularly important group who have the direct responsibility for and ability to make an impact on both building and portfolio level. Developers are also significant; their impact is often limited to new construction, a relatively small share of the building stock, but their impact will often set the conditions for a long time to come.

There are different ways in which real estate owners and developers can be influenced to manage real estate in a sustainable way. Price signals in the market indicating that sustainable management and investments are rewarded will encourage real estate owners and developers to care for their buildings in a sustainable manner. If markets fail to signal the socially optimal value of sustainability, regulators may use policy instruments to incentivize action in the desired direction by rewarding sustainable actions or by punishing the opposite.

The aim of this thesis is to explore the sustainability concept in a real estate context and to investigate how it is perceived and responded to by important actors in the real estate market, particularly real estate owners and developers. The more knowledge about what incentives actors have, the better are the possibilities to influence them on relevant levels to care for existing buildings and building portfolios in a responsible and sustainable manner.

Based on this aim, the thesis seeks to explore and answer the following questions.

1. How are aspects of sustainability perceived and handled by important actors?

2. How, in practice, have market actors handled sustainability related features?

3. Are there economic incentives for sustainability?

4. What else than economic rationality may explain sustainability ambitions?

The studies included in this thesis have been part of a broader research aim to study sustainability issues in the real estate sector and carried out more or less independently. The collected results can be used to draw learnings about the incentives for sustainable real estate for important actors in the sector. Six papers, listed below, seek to answer the questions from different perspectives and using different methodological approaches. The research questions will be handled in each of the papers to more or less extent.

Table 1 List of included papers and main research questions

	Paper	RQ
I	Incentives for Improving Energy Efficiency When Renovating Large-Scale Housing Estates: A Case Study of the Swedish Million Homes Programme	1, 2, 3, 4
II	Sustainable renovation strategy in the Swedish Million Homes Programme: A case study	1, 2, 3, 4
III	Organization of Laundry Facility Types and Energy Use in Owner-Occupied Multi-Family Buildings in Sweden	2, 3
IV	An empirical study of the behavioral response of developers and investors to the LEED rating system	2, 3
V	The impact of energy performance on single-family home selling prices in Sweden	1, 2, 3
VI	Who will close the energy efficiency gap? A quantitative study of what characterizes ambitious housing firms in Sweden	1, 3, 4

Although the research questions and the implications that can be drawn from the results can and should be placed in a broad context, the focus of the studies is mainly limited to existing buildings and their owners.

2 BACKGROUND

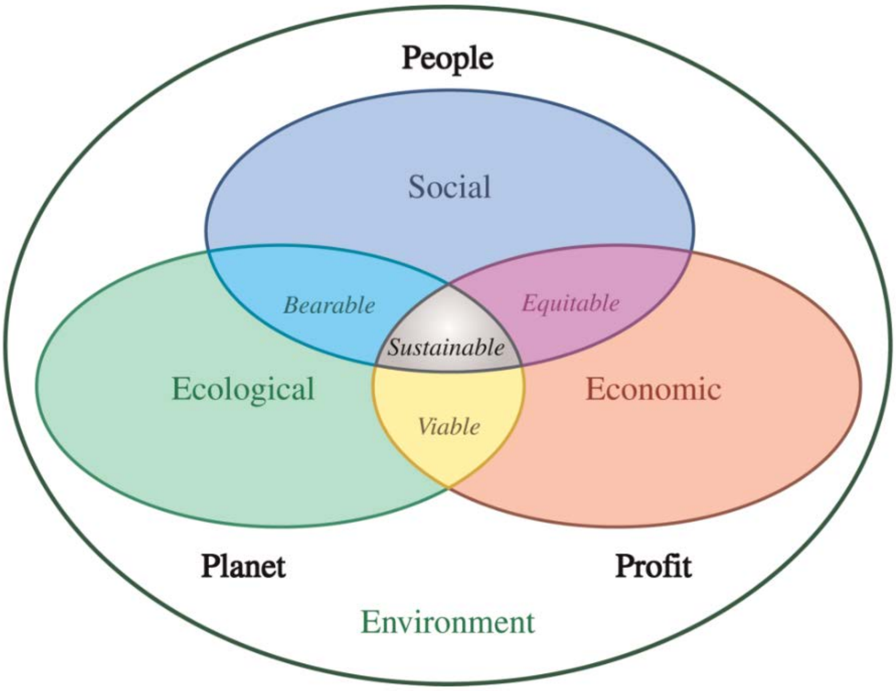
2.1 The sustainability concept

Ever since the UN report *Our common future* was released in 1987, sustainable development has been a widely accepted concept and a generally strived for state for society. One of the most long-lived accomplishments of the Brundtland report was defining that *sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (United Nations, 1987, p. 41).

In an economic definition, Stavins *et al*. (2003) propose that dynamic efficiency and intergenerational equity are two demanding yet necessary conditions for policy guidance. Although constant consumption at a mere subsistence level would fulfil the Brundtland definition of sustainability, a socially desirable level of consumption (broadly interpreted) would be one in which the economy is at the Pareto frontier. At this point of dynamic efficiency, the economy is maximizing social utility by exerting "non-wastefulness" and thus has the *potential* of becoming sustainable. To assure that the economy is actually made sustainable, inter-generational transfers can fulfil the intergenerational equity condition that the total welfare function is non-declining over time.

Today, the understanding of the concept sustainability in policy and academia is multidimensional; not only does it encompass environmental sustainability but also at least economic and social sustainability. Other dimensions that have been considered include cultural, historical and institutional sustainability (Botta, 2005). Figure 1 illustrates the three dimensions of sustainability recognized as "the three pillars" (Lehtonen, 2004). The interfaces show how the dimensions interact and the interpretation of an acceptable balance between each of the dimensions.

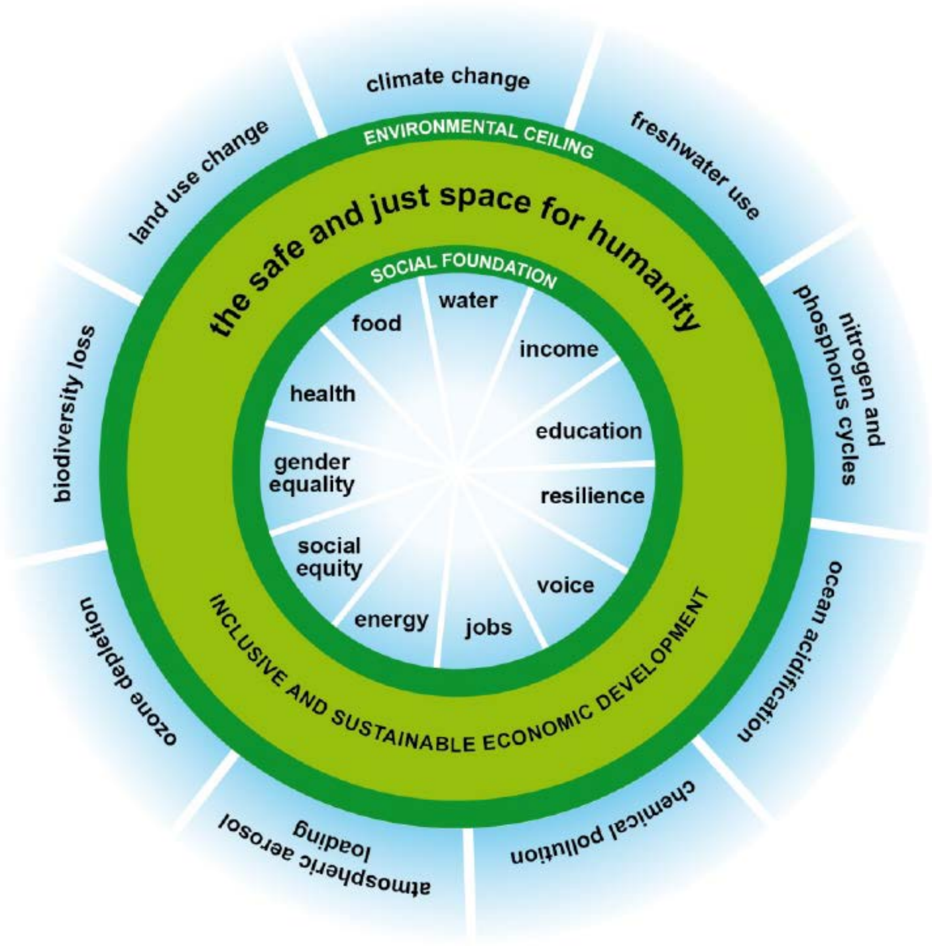
Figure 1 Dimensions of Sustainability - "the Three Pillars"



Source: Thomsen & van der Flier 2009

The three pillars model is widely familiar but is not the only way to illustrate how different sustainability dimensions need to be taken into account. Within the international policy framework, Raworth (2012) has suggested an analytical framework in which the planet's natural resources set the environmental boundaries, a ceiling for all human activity to take place within. This *includes* the pursuit of a just space, free from critical human deprivation. Sustainable development requires living within ecological as well as social boundaries to avoid ecological and social crisis. These boundaries are based on norms and guided by research, but it must be remembered that local as well as global scale matters, for all systems are interconnected. Building a social foundation and staying within ecological boundaries creates a conceptual framework in shape of a "doughnut" that can be seen in figure 2.

Figur 2 "The Doughnut": A safe and just space for humanity to thrive in



Source: Raworth 2012

The doughnut approach thus in some sense puts stricter demands on human activity in that it doesn't tolerate tradeoffs between dimensions that risk crossing tipping-points of Earth-system processes. At the same time, the dual aim it proposes is to move back to a safe environmental space and to move forward *all* human population into a just space.

Environmental (or ecological) *sustainability* is the most commonly assumed dimension out of the three pillars in figure 1. The dimension refers to a development that does not endanger natural resources, species and ecosystems (Anan & Sen, 2000). Raworth (2012) proposes quantitative indicators including buffer zones for nine critical Earth-system processes to provide a 'safe operating space for humanity' as seen in figure 2. Due to current human activity, the boundaries of climate change, biodiversity loss and nitrogen use have all been crossed already.

Social sustainability is the least well-defined of the three dimensions and it can even be argued that everything about sustainable development has a social dimension (Åhman, 2013; Littig & Grießler, 2005). Two commonly used approaches to assess social sustainability are through capabilities (of people to convert economic wealth into desirable outcomes) and social capital (in the form of norms, trust and reciprocity that improves the efficiency of society), and others include economic equity, livability, health equity, community development, social support, human rights, labor rights, social responsibility, social justice, cultural competence, community resilience, and human adaptation (Lehtonen, 2004; Adams, 2006). Some of these aspects are also included by Raworth (2012) (see figure 2). She notes that within the international relations framework, social priorities from governments are that people are well, productive and empowered and she also acknowledges that we have never had a state of social sustainability for all humanity but argues that reaching such a state should be top priority for policy makers. The 11 indicators that are proposed to operationalize social sustainability requirements can be seen at the center of figure 2.

Economic sustainability can be defined as maintenance of capital, for continuous generation of income (von Hayek, 1935; Goodland & Daly, 1996; Stern, 1997). A more useful definition for governments, firms and households need to account for private as well as social costs and benefits; benefit-cost analysis may thus be one useful application. By assigning monetary values to social costs and benefits and using a life-cycle economic (LCE) approach, government and firms may account for different types of future consequences using a financial framework. Minimized life-cycle costs (LCC) and non-declining capital (real estate) values are possible interpretations of the term economic sustainability (Stavins *et al.*, 2003; Goodland & Daly, 1996; Stern, 1997). Although the LCC approach can be criticized for oversimplifying and for not properly assessing environmental risks, it still provides a methodology that permits taking into account environmental impact over time and comparing them in a uniform framework (Gluch & Baumann, 2004). To complement these monetary assessments with qualitative concerns, a balanced scorecard may also be used (Figge, 2002).

2.2 Corporate Social Responsibility

Over the past decades, firms have increasingly been engaging in activities beyond their core business that primarily benefit others than themselves. Firms devote time and resources in activities that go beyond their legal obligation, for example to compensate for some of the negative impact on the environment that their business causes. This type of prosocial behavior, i.e. behavior that primarily benefits others, have been labeled corporate social responsibility (CSR) and connects to the direct ethical, environmental, social and governance practices of the firm. The related term Socially Responsible Investments (SRI) refers to investor practices used to take into account such management practices, but which investors cannot directly influence (Scholtens & Sievänen, 2013). To advance the cause, CSR and SRI advocates commonly maintain a win-win argument, but tradeoffs related to corporate sustainability are probably necessary even if the extent of tradeoffs needn't be too discouraging (Hahn *et al.* 2010).

2.3 The building sector and its characteristics

Two of the most important characteristics of real estate are that it is static in space and durable in time. Once constructed, the ecosystem with which a building is interacting and the local community to which a building creates social pattern alterations, cannot be unchanged. Even in the relatively rare case of demolition, there will still remain tangible and intangible traces of the built environment in nature.

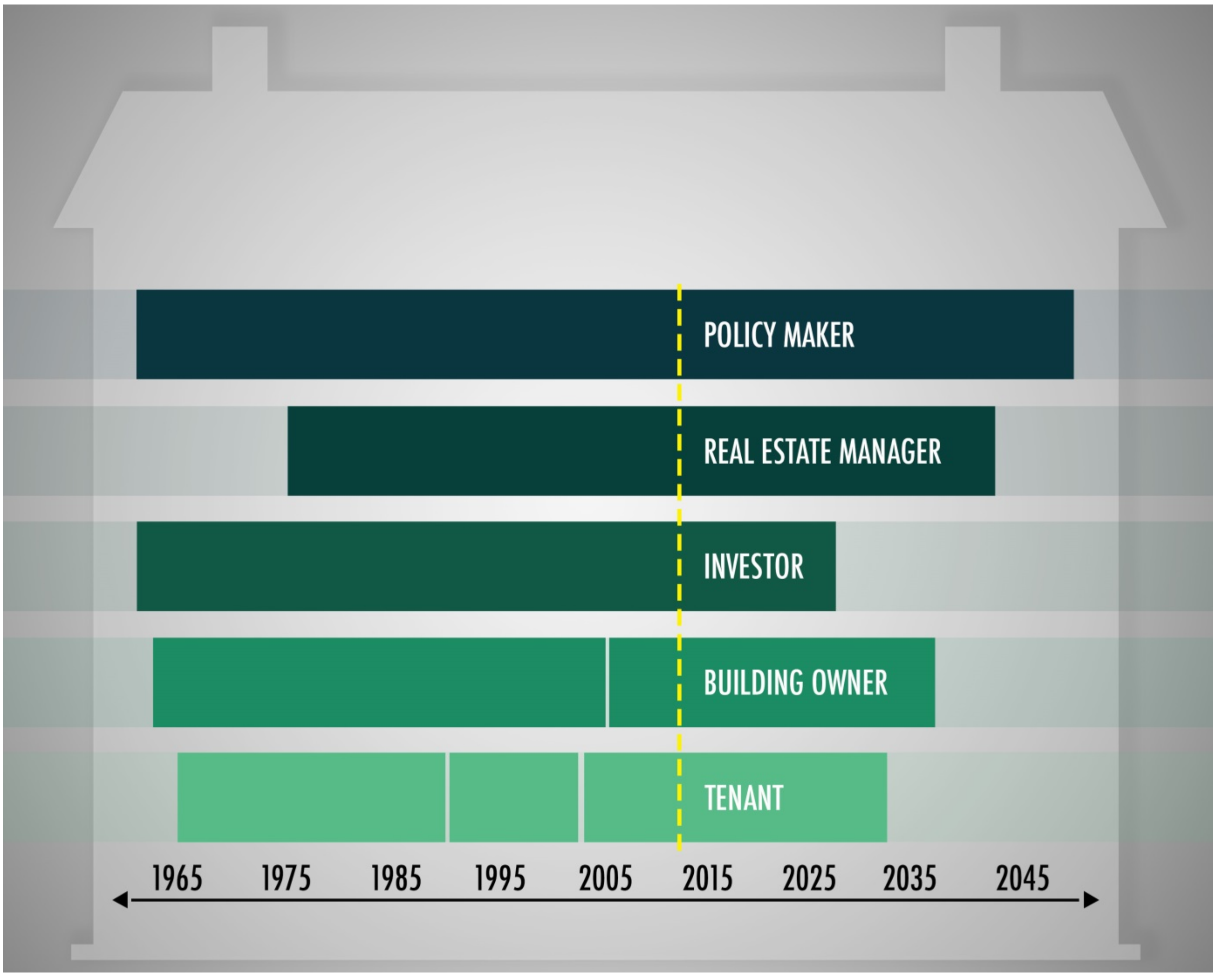
Durability of the built environment implies that the way in which buildings are constructed, at least in Europe, will endure for decades ahead. The existing building stock is substituted by less than 1 % per year, which means that most of the buildings we will be using in 50 years have already been built (Ravetz, 2008; Thomsen & van der Flier, 2009). This is not to say that the role and function of the buildings cannot vary over the course of time; changing needs and demands continuously lead to functional obsolescence in addition to technical obsolescence occurring when installations need to be replaced and the building envelope needs mending. At these points in time, the way we use the buildings may change but the physical structures largely remain unchanged.

The built environment also serves multiple purposes and can be analyzed from different perspectives: serving as shelter, comfort, pleasure, security, visual experience, center for administration, artistic expression, meeting point, source of income and so on. Thus, buildings and their use will have economic, social, legal, technical, environmental and cultural dimensions depending on whose perspective and for what purpose we decide to analyze.

Figure 3 is an attempt to visualize some of the complexity of real estate by assigning a timeline to the interest of each actor/perspective related to a particular object. “Present” is at the intersection of the horizontal axis, with “past” to the left and “future” on the right. For different actors, the relevant scale may be a dwelling, a building, a building portfolio, a city, and etcetera and actors sometimes have interest in multiple scales. Real estate is handled at different scales by different stakeholders who all act and are affected in relation to their respective time horizons, which gives them different incentives for action. At the dotted line, looking ahead, the involved actors will make decisions depending on the outcome, their respective time horizon and their ability to influence.

Each line along the time axis is an example of time horizons belonging to different stakeholders, or in other words, the lifecycle of the structure (building, neighborhood, etc) as it appears to them. For policy makers, the top line may correspond to the goals to improve energy efficiency in the built environment by 2020/2050. The real estate manager, as an agent of the real estate owner, will have an interest in the building over its entire building life cycle but frequently the intensity of attention will increase as a function of building age. An investor may be short-sighted or, as in the case of many institutional investors, have a rather long time-perspective. The building owner may have had the building constructed in the 1960’s and either kept it until now or sold it to a new owner, as suggested by the break in the timeline. In addition to these, a line could be added for the developer who has limited interest in time with respect to the building but who will provide the conditions for future operations and activities in it.

Figure 3 The built environment over time from different stakeholder perspectives



Source: Nyström, 2014.

Using this illustration, some key points in time over the lifecycle of some building (or other element) can be pointed out, for example to visualize decision points and opportunities to improve real estate. For a building it might be as simple as marking the stages of construction, maintenance, (reinvestment) and demolition. It may also be used for comparison; two stakeholder perspectives will often have different lifecycles and decisions made now will thus impact them differently. Assuming a neighborhood needs renovation, the buildings as whole and how they are used may still have at least another 40 years if renovated wisely. To optimize the technical, environmental, social and economic outcome at, the involved perspectives should all be considered.

In summary, when we analyze the built environment, for example in order to make policy suggestions, we should remember what perspective and time frame we are considering. Over the technical lifecycle of a building, there are few opportunities to make any substantial change and improvement to the conditions of building performance, so to make most impact we should ask ourselves at what scale, at what point in time and for how long do we wish to act? Having established this, we can move on to analyzing what actors have a possibility to act on this scale and within this time frame.

2.3 Real estate and sustainability

The sustainability concept can readily be applied to the built environment. It is easy to see the connection between how the built environment uses resources from the natural environment in its creation, how it alters the natural environment in its establishment and how it impacts the natural environment in its being. The same is also true socially and economically, albeit sometimes not as straightforward.

Applying the three dimensions of sustainability to real estate highlights the connection; the interconnectedness of people, profit and planet are manifested on various scales in buildings and neighborhoods through the (impact of) materials and technology used, through the experience and behavior of occupiers as well as through the economics of buildings, real estate portfolios, real estate firms and governments through net operating incomes (NOI), returns, profits and net taxes.

Application of the sustainability dimensions to real estate

Environmental sustainability

In this thesis, this dimension has been interpreted partly on a general environmental level measured by environmental certification schemes and indices, but also using energy consumption as an indicator of sustainability in a real estate context (Reed *et al.*, 2009; Toller *et al.*, 2011; Toller *et al.*, 2013;). Using energy consumption to indicate the level of sustainability can be motivated for several reasons. First, energy consumption is one of the main contributors to real estate's environmental impact; reducing energy consumption in the real estate sector will reduce climate impact (Toller *et al.*, 2011). Second, energy consumption is relatively easy to monitor and energy performance data is readily available for many types of real estate (Toller *et al.* 2013). Thus, for measuring purposes, there are clear advantages to using energy as an environmental indicator. Third, energy consumption is more easily understood by the general public than more complex measures of sustainability, implying that many market actors will be aware of this aspect of real estate and see the connection between their activities and sustainability. Fourth, energy consumption has a clear economic connection and energy performance can easily be given monetary values. Energy use may also be organizationally divided, with interesting impacts on incemtives (Bonde, 2012). Finally, energy consumption has a social dimension; less so in Sweden if compared to many other countries considering the fuel poverty aspect, since the Swedish rental sector is dominated by inclusive rent. Nevertheless, the endogenous determination of energy consumption does for example influence the well-being of tenants depending on their choice of energy consuming activities.

In environmental terms, real estate also uses massive amounts of resources in construction and operation; reducing the initial use and reusing what has already been used once would significantly improve sustainability in the sector. Over the course of a building's life, it also produces waste, emits pollutants and embodies hazardous substances that imply a risk for its users (Toller *et al.*, 2009; Willmot Dixon Group, 2010). Naturally, minimizing the environmental impact of buildings over the course of their lifecycles is at the center of interest for environmental sustainability.

Social sustainability

The use phase constitutes the majority of a building's life, and the majority of human life is spent indoors. Thus, in social terms, buildings set the frame for our social interactions and have an enormous potential in shaping our experiences, physically as well as psychologically. The geographical location of our homes and whereabouts will also condition the connections we make with other people, which in turn may influence the well-being of us as individuals and of us as a society. Where people want to live and where they are able to live are important questions related to social sustainability (Dempsey *et al.* 2011).

Dempsey *et al.* (2011) have made an attempt to define urban social sustainability on a neighborhood scale for a planning context which is useful for the purpose of this thesis as well. In their review of the literature, the authors establish that there are numerous non-physical as well as (predominantly) physical factors that contribute to urban social sustainability. Examples of non-physical factors relevant for a real estate context are participation, health, quality of life and well-being, social capital, safety, mixed tenure, sense of community and belonging and residential stability. Examples of physical factors include attractive urban realm, decent housing, local environmental quality and amenity, and sustainable urban design.

The listed factors (or the absence thereof) in Dempsey *et al.* (2011) are neither absolutely good nor absolutely bad; urban social sustainability is a dynamic concept to which the listed factors may contribute individually or in combination in a positive or a negative way. According to the definition the authors then propose, two dimensions are at the core of urban social sustainability: social equity and the sustainability of community. The first dimension is related to social and environmental exclusion; note that a society is equitable if there are no exclusionary or discriminatory practices hindering individuals to participate in society. This may be measured by assessing accessibility, and how equal access is to key services, key facilities and transport. The second dimension, sustainability of community, is related to social capital and social cohesion, or the ability of society to sustain and reproduce itself at an acceptable level of functioning.

Three factors related to the collective aspects of life, which is what the sustainability of community dimension above relates to, are particularly relevant for real estate management: community stability, pride/sense of place and safety and security. Community stability can be indicated by residential turnover, although residential mobility may also improve the overall sustainability of a particular neighborhood. Pride and sense of place can affect the perceived quality of a place and thus change or reinforce the social interaction and local norms. Safety and security is basis for any other positive social activity (Dempsey *et al.* 2011).

Economic sustainability

If economic sustainability is defined as maintenance of capital for continuous generation of income (von Hayek, 1935; Goodland & Daly, 1996; Stern, 1997), real estate can be defined as economically sustainable if it maintains value and generates a surplus for current and future societies, given levels of uncertainty and risk. This may be on a building level, considering lifecycle costs and revenues as well as real estate long-term values. It could also be at a social level, considering public income and spending for construction and management of real estate and its occupiers. The allocation of costs and benefits may be unevenly distributed between stakeholders, but a total net surplus in the value of real estate can still be seen as sustainable and Pareto optimal even if the distribution needs to be addressed by policy makers.

Sustainability rating tools

There have been many attempts to measure and communicate the degree of sustainability of the built environment. A range of national and international environmental schemes have been launched over the past few decades (Reed *et al.*, 2009; Malmqvist et al., 2011). The rating schemes illustrate the connections between buildings and sustainability, and to account for the negative impact of the built environment on the natural environment, the connections are graded so that the less negative impact or the more positive impact of a building or neighborhood, the better is the resulting score. What and how the rating tools measure differs; some include a whole range of environmental and social attributes that are weighed together as an index, others focus on one or only few aspects and/or separate the assessment for each of the attributes. There are assessment tools for most levels of the scale, some focus on the sustainability of extraction materials and production of components, some on the sustainability of individual buildings, some on the sustainability of neighborhoods. The purposes of these tools have been to integrate sustainability features in the assessment of buildings; by overcoming market asymmetry and informing consumers of the benefits of sustainability. The aspiration has been to enable a better valuation of relevant building aspects (Reed *et al.*, 2009; Lützkendorf & Speer, 2005).

There are examples of CSR strategies in housing management which indicates that it may be profitable in the long run for firms to take responsibility for run-down areas beyond what is traditionally considered to be their responsibility (Blomé, 2012).

In order to fulfil all of the sustainability dimensions, the interpretation of sustainability may need to be more holistic and pragmatic than that of formal systems (Poveda & Lipsett, 2011). Therefore, in this thesis I do not limit analysis to sustainability which is being measured using formal systems. Regardless of the involved actors' sustainability ambitions, the degree of sustainability in one or several dimensions will be analyzed.

2.4 Important actors

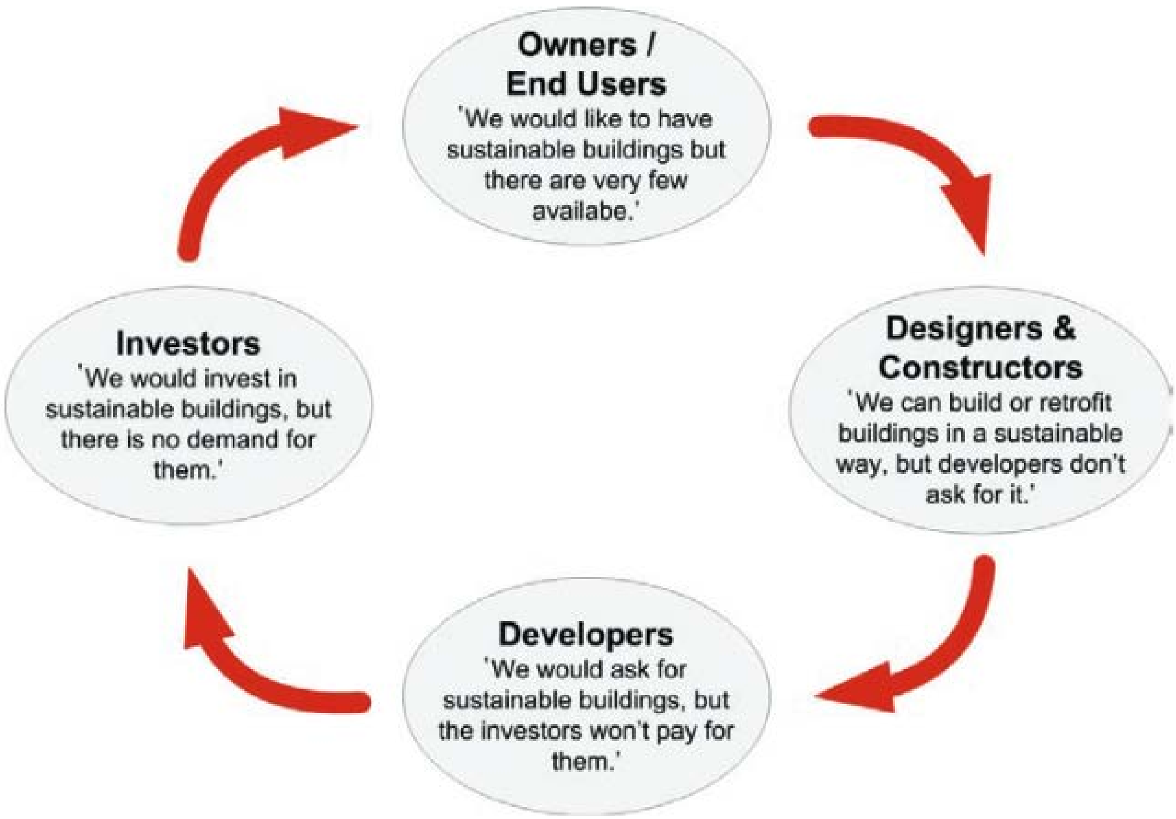
In this thesis, I have chosen to focus on the actors who have a direct possibility to influence the sustainability of real estate (save policy intervention); actors on the supply side of real estate. In order to analyze incentives, it is necessary to identify who have an interest and who are active within the sector, which can be seen as a precondition to later being able to counteract possible unsustainable behavior with policy measures.

Two groups are of particular interest. Developers have great possibilities to decide what standard the building will adhere to for a long time from erection so their incentives to behave responsibly will be important for future buildings. However, at the current rate of renewal of the stock, most of the buildings we will use in 50 years have already been built. Therefore, the incentives of real estate owners who manage the existing stock and whose decisions also influence greatly the social dimension of real estate are important.

A third group that would be relevant to consider are investors who buy and sell real estate (shares) but these are only briefly mentioned in one of the papers. It deserves mentioning, however, that they play an important role in what has been described as the circle of blame, seen in figure 4. In a circle of blame, each actor in the supply chain claims that they would supply sustainable real estate if only the next link would create the necessary preconditions for it. The opposite of the circle of blame is the situation depicted in figure 5, in which all the stakeholders in the market send virtuous feedback to each other, creating favorable conditions for sustainable real estate. This also includes the demand side of real estate, which influences the sustainability of real estate indirectly. For example, CSR on behalf of office tenants may impact their willingness to pay for sustainable office space which reinforces the virtuous loops of feedback and adaptation in figure 5 (Eichholtz *et al.*, 2009).

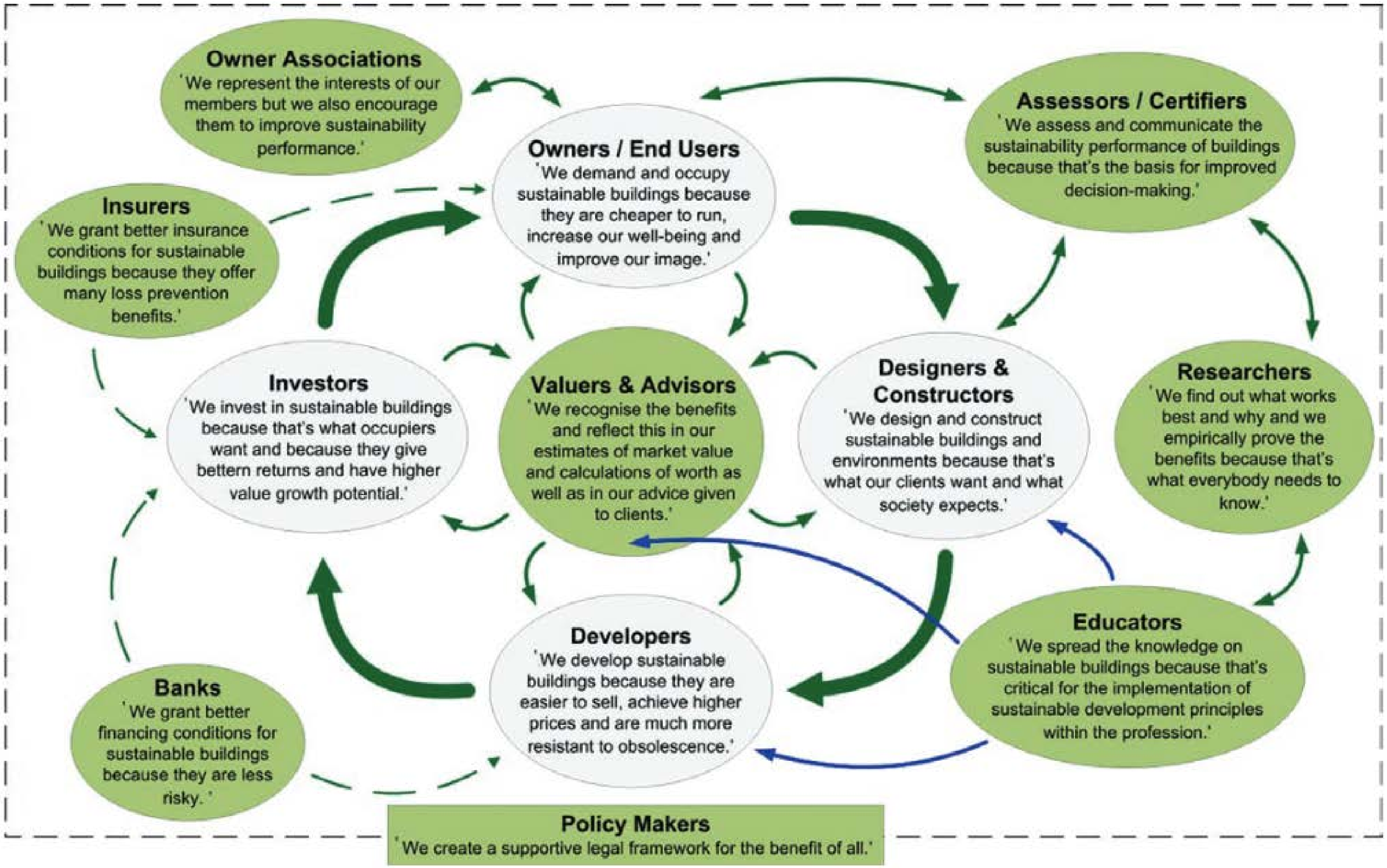
To escape a situation in which each actor sits tight awaiting the move of the others and instead arrive at a situation of positive feedback such as that depicted in figure 5, actors and their respective time horizons and domains need to be identified and their incentives need to be analyzed, which is what this thesis aspires to do.

Figure 4 The vicious circle of blame



Source: RICS Europe 2008

Figure 5 Virtuous loops of feedback and adaptation



Source: RICS Europe 2008

3 THEORETICAL FRAMEWORK

Assuming that social welfare can be increased by improving sustainability in at least one of the three dimensions, what could make firms in the real estate market take action to change this?

Within neo-classic economic theory, actors are rational and respond to economic incentives. By maximizing household utility and firm profits, an efficient outcome is achieved. The state only intervenes to correct market failures such as externalities, public goods and information asymmetry or to redistribute incomes and wealth to ensure a fairer outcome. Thus, in reality, firms supposedly act according to price signals in the market and if the resulting outcome is socially undesirable, the state provides a regulatory framework and modifies price signals by imposing taxes and/or providing subsidies. These rewards and punishments aim to align private interests with social interests. Thus, according to this view, unsustainable real estate is attributable to the lack of price signals, which have not (yet) been corrected by policy measures.

With the development over time of economics, especially with the contributions from behavioral economics, the view on individuals and firms as acting rationally and only in self-interest has been challenged. Simon (e.g. 1955; 1959) made important contributions by drawing insights from psychological research to nuance the picture of the profit maximizing firm and accounted for complexity in decision-making by introducing concepts like bounded rationality and satisficing actors. It has also been suggested that firms may have other objectives than maximizing profits and that “organizational slack” may introduce complexity in the firm’s behavior in the short run (Grossman & Stiglitz, 1977; Simon, 1979; Cyert & March, 1963). Other contributions to the behavioral stream suggest that fairness may contribute to utility, which contradicts the idea of individuals only acting in self-interest (Bandiera *et al*, 2005; Fehr & Schmidt, 1999; Bénabou & Tirole, 2006). This implies that “sustainable decisions” (decisions leading to a more sustainable development), even if not being part of a profit maximizing strategy, could be an acceptable behavior of the firm if it gives a satisfactory profit and saves the firm from further search for a profit maximizing strategy. It also implies a challenge for policy makers who need to consider a wider array of possible motivations and responses when designing policy instruments.

There may be barriers to sustainability, or “aggravating circumstances” under which efficient outcomes are harder to reach. Some of these barriers, like transaction costs, are not market failures but nonetheless impede the improved sustainability of real estate. The preferences and objectives of the various actors who organize themselves in firms may differ substantially and there is a challenge to motivate actors to work against the same or at least a similar goal (Simon, 1991; Levinthal, 1988). By all means, coordination and motivation problems are present at all levels in society, from government level where setting sustainability (and other) goals requires massive coordination to a single pair of individuals who agree to a small transaction and need to negotiate on the terms. The fact that individuals agree to organize themselves within the same organization instead of each pursuing their own goals can be partly attributable to transaction costs; if transaction costs are large it will be attractive to individuals to repeatedly cooperate to obtain a certain level of utility, even if it means that satisficing instead of maximizing is necessary (Coase, 1937; Williamson, 1979; Simon, 1991). When individuals are organized into one entity and a group of individuals work to fulfil the goals of the owner of the organization, it may carry problems of split incentives since one or several of the employees (the agents) may have different views and wishes than the owner (the principal). Conflicts of interests between the firm and outside stakeholders or within the firm requires that incentives are provided that align interests to that the employees or the agents act in accordance to his or her will (Levinthal, 1988). Split incentives make the outcome less efficient than it would be if they were working to maximize total utility. Split incentives in trade situations require more coordination to arrive at an optimum and high transaction costs can then lead to a situation where this coordination is not done (Ross, 1973; Eisenhardt, 1989; Williamson, 1981). The vicious circle of blame in figure 4 is an illustration of what may happen if market actors don't have incentives to reach the same objectives.

Information asymmetry between agents within an organization or between market actors aggravates the problems of coordination and motivation. Typically, the producers know more about the performance of their products than their (potential) customers do but may be unwilling or unable to transmit this knowledge. Consumers, on the other hand, know how much they value the products but may not wish to reveal this to producers and other customers to be able to keep the price paid low(er). In addition, information asymmetry aggravates agency problems, for example because of the difficulty to monitor agents (Akerlof, 1970; Eisenhardt, 1989).

There are organization strategies that reduce the problems of asymmetric information, agency problems and lower transaction costs. To improve conditions for coordination and motivation between stakeholders, agents may for example design their contracts so that they align interests and signal to the other part about their honest intentions (Hinnells, 2008; Bonde, 2012; Spence, 1973). Firms may for example provide economic incentives as a way to signal trust in a relationship or engage in long-term cooperation, both of which lower the transaction costs and reduce information asymmetry (Kadefors & Badenfelt, 2009; Eriksson, 2010). Furthermore, signaling by providing information about the quality, performance and service of real estate in the market will decrease information asymmetry and lower transaction costs for consumers. They may then be willing to pay for certain sustainable attributes which creates and reinforces market signals (Lützkendorf & Speer, 2005).

Given the description above, two things can be noted, namely that a) profit maximization does not necessarily have to be the ultimate goal for firms (which may complicate how they respond to policy measures) and that b) coordination and motivation may be needed at multiple levels in order to overcome barriers and achieve a higher degree of sustainability in real estate.

Prosocial behavior and corporate social responsibility

In the neo-classic free market scenario, firms act sustainably if it is encouraged in the market and thus generates (more) profits. In the case of government intervention to increase the degree of sustainability, a minimum requirement of sustainability may be imposed by the state, information asymmetry may be reduced and (relative) prices may be altered through taxes or subsidies to make sustainable behavior more attractive to the firm.

Behavioral economics on the other hand suggests that firms may act sustainably even if it is not strictly profit maximizing, depending on search costs and stakeholder preferences. A spectrum of possibilities and various levels of sustainability that the firm may aim for may then be considered at least in part as prosocial behavior and firms who undertake them engage in corporate social sustainability (CSR).

Brief & Motowidlo (1986, p. 711) defined prosocial organizational behavior as *behavior which is (a) performed by a member of an organization, (b) directed toward an individual, group, or organization with whom he or she interacts while carrying out his or her organizational role, and (c) performed with the intention of promoting the welfare of the individual, group or organization toward which it is directed*. Prosocial behavior can (but does not have to) be organizationally functional in that it benefits the organization in fulfilling its objectives, it can (but does not have to) be role-prescribed as a formal requirement of the job and the prosocial behavior may target individuals within the firm, consumers of the firm or the organization as a whole. Prosocial behavior may arise as a result of individual characteristics or as a result of organizational characteristics such as reciprocity norms, group cohesiveness, role models, reinforcement contingencies, leadership style organizational climate, stressors, contextual determinants of organizational commitment and factors that affect individuals' mood and feelings of satisfaction (intrinsic motivation).

Bénabou & Tirole (2003; 2006; 2010) suggest that people (and firms) may engage in prosocial behavior for three reasons: material self-interests, altruistic motivation and social/self-image concerns. Theories about prosocial behavior thus complement the traditional way of viewing incentives as (monetary) rewards and punishments with the psychological concepts intrinsic and extrinsic motivation. Extrinsic motivation (motivation from outside the individual) includes the traditional incentives of material rewards and punishment but may also encompass intangibles like praise or shame. Intrinsic motivation is the internal satisfaction obtained from performing a task and this may or may not be aligned with extrinsic motivation.

Image concerns, are related both to how individuals' see themselves (or the firm they represent) and to how they experience other peoples' views. Self-image is intrinsic motivation based mainly on own believes and values. Social image is extrinsic motivation mainly based on social norms. Individuals may act prosocially as a response to image-concerns, either as a way of honor-seeking or as a way of avoiding stigma (Bénabou & Tirole, 2010).

Crowding out of intrinsic and extrinsic motivation

Image concerns, whether social or self-image related, may however result in an adverse impact that could crowd out externally provided incentives like policy tools to encourage prosocial behavior. Four potential cases are considered (Bénabou & Tirole, 2006; 2010).

- Publicity or material incentives that are provided to increase participation in a certain prosocial activity, may give the individual or firm that engages in the activity concerns that others mistake altruism for image-seeking or greed. This may result in self-limiting of prosocial behavior and 'over-justification'.
- The choice of prosocial behavior may be based on its visibility rather than what is most socially righteous, resulting in a socially suboptimal outcome.
- Social prestige is a positional good, which implies that others' good deeds may result in a 'reputations stealing' externality, reducing the attraction of the prosocial act in question.
- Doing good in one dimension may result in a justification of mediocre or bad behavior in another dimension (moral credentialing).

Frey & Jegen (2001) give an overview of how material incentives may reduce participation in prosocial behavior, such as blood donation. Crowding-out may also work in the opposite direction, if extrinsic punishment "encourages" bad behavior by undermining the 'internal justification' as suggested by Akerlof & Dickens (1982), which was later supported by results from Gneezy & Rustichini (2000). The second point is also of importance in relation to the concept of 'greenwashing', i.e. when firms try to free-ride on other firms' environmental and social efforts to satisfy consumers' demand for ethically sounder goods. Using labels to signal sustainability makes it easier for firms to convey their virtuosity to customers, compared to firms who claim to act sustainably but only try to draw advantage of information asymmetry (Zaman *et al.*, 2010; Parguel *et al.* 2011).

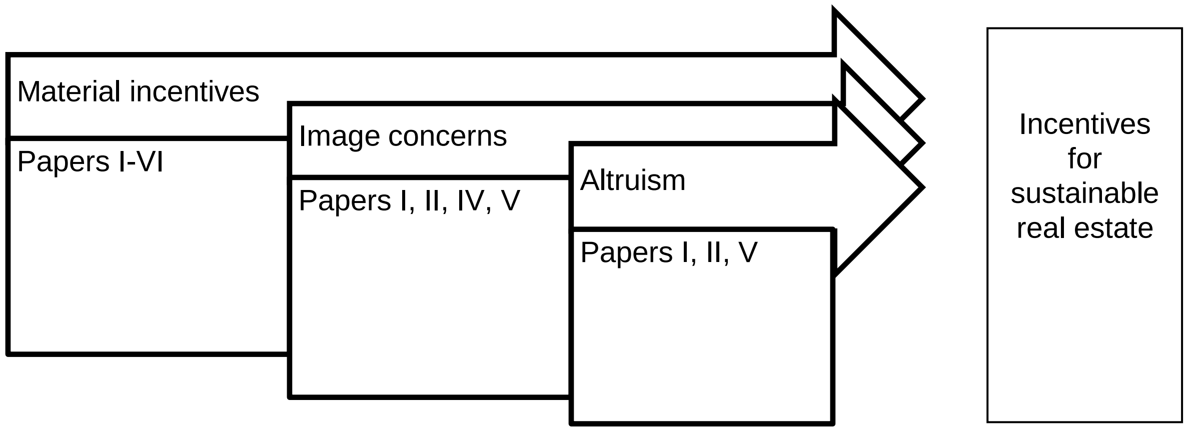
Image concerns are also endogenously determined by the proportion of people who engage in the behavior. Honor-seeking is more effective when few people are carrying out the same prosocial act resulting in high social prestige, whereas it is more relevant to talk about stigma-avoidance the more people who engage in the behavior such that it is considered the decent thing to do. Neither of these cases require high (material) incentives since that should obscure the true motives behind the act.

Bénabou & Tirole (2010) also suggest three theories as to why firms would engage in corporate social responsibility. The first is a win-win argument, compatible with long-term intertemporal profit maximization. The two last arguments express a desire for delegated philanthropy driven by altruism, material incentives or social or self-image concerns. The citizen-delegated philanthropy argument suggests that stakeholders are willing to give up money in order for the firm to carry out socially responsible actions on their behalf. The insider-initiated corporate philanthropy argument suggests that management uses the firm to further social goals of their own, similar to that Brief & Motowidlo (1986) suggested. In the latter case, the objectives of management and owners may not be aligned but it may be hard for the owners to know this.

3.1 Appearance of the theoretical concepts in the included papers

Acting sustainably (or not) for material incentives, i.e. in self-interest, will be discussed from different angles in all of the six papers. Acting sustainably out of image concerns is treated in papers I and II but also in paper IV and V, where "other" possible drivers for acting more sustainably are proposed. Acting sustainably for altruistic reasons is treated similarly in papers I, II and VI. The incentives provided by the market or by policy makers will set the frame for firms and other stakeholders. Together, the three types of drivers are studied to learn more about incentives for sustainable real estate as illustrated in figure 6.

Figure 6 The appearance of theoretical concepts in the included papers papers



Situations related to barriers for sustainable real estate are also relevant to consider and the concepts and conditions of agency theory, asymmetric information and transaction costs will appear in the papers according to table 2, where also the appearance of the three typer of drivers to engage in prosocial behavior suggested by Bénabou & Tirole (2003; 2006; 2010) are listed.

Papers I-III and V can be analyzed using agency theory. Firms have many objectives and by acting in a certain way, firm employees carry out actions that may or may not be what the firm owners want them to carry out (papers I, II and V) or it may act at a satisficing level given the tradeoff between different objectives that the firm has to take into account. Furthermore, construction firms build in a way that may or may not be in the interest of the prospect residents (paper III). Asymmetric information, signaling and transaction costs are concepts mainly treated in papers IV and VI, both of which study how labeling has been adopted as a way to overcome information asymmetry and some of the consequences this may have in the market.

Table 2 The appearance of theoretical concepts in the included papers

Paper	Main type of driver for sustainability			Barriers for sustainability		
	Material incentives / Self-interest	Image-concerns	Altruism	Agency/ split incentives	Asymmetric information	Transaction costs
I	x	x	x	x		
II		x	x	x		x
III	x			x		
IV	x	x			x	x
V	x	x	x	x		
VI	x				x	x

Asymmetric information along with split incentives often results in a principal-agent (PA) relationship between stakeholders. The principal-agent concept is often used to exemplify tenant-landlord dilemmas, like when tenants pay an inclusive rent that covers most of maintenance and operation costs, in which case the tenant has little incentive to behave in a way that reduce these costs. In this context, however, it is more straightforward to think about it as firms managing their buildings with a short- or long-term horizon, which may influence for example their choice related to renovation to be in line (or not) with the owners' preferences, or developers having a shorter time-horizon than the future residents.

The PA concept may also be applied to the transaction between developers and housing firms or households. Since developers may be interested in minimizing upfront production costs to maximize total profits whereas housing firms are more interested in reducing operation and maintenance costs to maximize their profit, the incentives they have and the choices they would like to make will most likely differ. If housing firms recognize the value of lower lifetime costs, they may have a higher willingness to pay upfront for buildings if there is credible information that the building has lower costs for operation and maintenance, which may imply that developers may gear production so as to meet this demand.

A high degree of asymmetric information may increase the need for signaling in the market to convince the other party of the performance of its own product or service. One obvious in the case of buildings is certification of the product, like Energy Performance Certificates and environmental classification systems.

Transaction costs are essentially interpreted as search and information efforts related to informing oneself about what really is sustainable and choosing the most sustainable option. Signaling decreases this cost whereas compromises may have to be made to arrive at sufficiently sustainable. To conclude, when applying the economic concepts to the building sector the ultimate interest is to analyze what incentives actors have and what conflicting objectives there may be.

4 A MIXED METHODS APPROACH

This thesis has been carried out using a mix of methods, one method at a time or a combination of methods for each of the included studies. The choice of method(s) was motivated by the nature of the research questions at hand and/or the availability of data. Some research questions were approached in an inductive way; indications of a phenomenon or recent changes within the field called for investigation and documentation without necessarily having a hypothesis beforehand. Other research questions were approached deductively, starting from general theories, stating hypotheses and collecting data to support or reject the hypotheses.

Choosing a mixed methods approach based on the research question(s) follows the tradition in Building and Real Estate Economics at the department. The strength of this approach is that it allows the study of the field from a micro and a macro perspective and by doing so the results add to the research field in many ways (Creswell & Clark, 2010). It also gives an opportunity to supplement and address weaknesses of the qualitative and the quantitative results respectively and add insights. Weaknesses of mixed methods approaches may be that it is hard for a single researcher to carry out all of the work, they require understanding of multiple methods and the appropriate use of which one when, (Johnson & Onwuegbuzie, 2004). Below is a description of how the methods were chosen. The research methods are described in more detail in each of the individual papers.

4.1 Learning how and why: Exploratory approaches

One important aspect of the overall research aim has been to gain greater knowledge about the field and the behavior of one type of actors, the real estate owners or in this case housing firms, in how they perceive and handle aspects of sustainability. This can be seen as a first out of two step of an exploratory sequential design, where insights from qualitative exploring later can be used for quantitative generalization (Creswell & Clark, 2010). Housing firms need to handle technical and environmental issues but also social and economic issues which makes them interesting for the purpose of studying a multi-dimensional interpretation of sustainability. All of the research questions were relevant for this aspect.

The complexity of real estate owners decision making and the need to balance many objectives were the main aspects that lead to the decision to use case studies for papers I and II. By doing so, the aim was to get a deeper understanding of if and how (housing) firms' consider sustainability related matters. The specific renovation context highlights the tradeoffs firms need to manage. The empirical material was mainly collected through interviews.

Incentives for Improving Energy Efficiency When Renovating Large-Scale Housing Estates: A Case Study of the Swedish Million Homes Programme.

At the beginning of the study, the understanding of how firms handled these issues was limited and the first priority was to get an overview of what was important to real estate owners. The study served to get an idea of important tendencies among Swedish housing firms and such mapping out is a precondition for further studies.

A multiple case study approach based on interviews with housing firms was chosen for several reasons. First, multiple cases permitted to get an overview of energy efficiency approaches in firms that differed e.g. in terms of size, ownership and geography. Second, the personal contact of an individual interview in which the firm representative was allowed to speak freely within the limits of a questionnaire gave an idea of what the firms wanted to highlight. Third, semi-structured interviews gave the chance to ask follow-up questions and enabled a deeper understanding of the lines of reasoning and explanation(s) for the different approaches.

Sustainable renovation strategy in the Swedish Million Homes Programme: A case study

This aim of this study was to document one approach to sustainable renovation and to assess its relevance, applicability and adoptability in the Swedish multi-family context. The study is a proposed operationalization of the three rather abstract dimensions of sustainability that housing firms need to balance so that it becomes useful to them. Although this case represents but one approach, the concept and its dimensions can still be questioned and discussed using one case only.

The complex decision making and the necessary trade-offs between sustainability dimensions motivated an interview based single case study to gain in-depth understanding of the firm and its strategy. The case was strategically chosen based on prior knowledge about the firm, which has made a conscious choice of renovation strategy and has an image of being responsible. Within the firm, representatives of the main divisions and functions have been interviewed to get the views and opinions of those who may need to make different priorities so that the assessment wouldn't be dominated by the perspectives of only a few persons, a sort of triangulation. Representatives of other stakeholders – actors who influence and are influenced by the firm's renovation strategy – were also interviewed to allow a fair assessment from a broader point of view. In this way, not only could the sustainability concept be assessed in the broad sense that was the aim of the study, but various views could be compared and the analysis calibrated.

4.2 Learning if and how much: Descriptive approaches

Papers I and II mainly build on the actors' self-reported sustainability ambitions and efforts. However, talk may be "cheap", so in addition to knowing more about how market actors say that they do to be sustainable, it was considered important to learn more about what they actually do. From this perspective, it was useful to study developers who have a shorter decision making process compared to a housing managing firm. Developers may change the orientation of their production faster, for example by adopting environmental certification schemes, and since the output "new construction" is a flow variable the results will be visible faster. Two research questions were of particular interest for these two papers, namely "2. How, in practice, have developers handled sustainability related features?" and "3. Are there economic incentives for sustainability?"

Two papers cover developers and their actions from a sustainability perspective. Paper III looks at developers' construction practices in new construction regarding the provision of laundry facilities and paper IV looks at how developers who have adopted LEED certification schemes have responded to how the LEED system is designed. In these two cases, it was deemed more useful to look at aggregate data to discover overall trends, rather than investigating individual cases.

Organization of Laundry Facility Types and Energy Use in Owner-Occupied Multi-Family Buildings in Sweden

In the study about laundry facilities reported in paper III, the developers did not necessarily have any pronounced sustainability ambitions. The consequences, however, of a systematic (perhaps unconscious) change in building practices, may impact the degree of sustainability in the built environment. Therefore, the most important contribution of this study was to establish if the early observations were indeed sign of a major change in construction practices. To document building practices then and now would give a starting point for future investigations.

The original approach of this study (beyond the scope of this paper) aimed to track cost increases and quality changes in construction over time which made the approach exploratory (Borg & Song, 2014). On-site visits were made using a checklist to document older building practices, without any preconceptions about what would be found. To follow up the indications in the exploratory stage, that building practices concerning laundry facilities have changed in recent years, a documentation of how laundry facilities are built was initiated. The on-site observations were crucial to identify older building practices since no documentation is available from developers about what and how they used to build. On the contrary, information about recent and current development projects is readily available online or only an email away, so surveying firms' websites was an efficient way of collecting this data.

When the change was confirmed in the first stage, focusing on the impact of the change on energy consumption meant the collected data had to be complemented by estimating how this could be influenced by appliance performance and user behavior. In lack of available data related to the investigated situation, a simulation proved useful to test plausible scenarios. This method is a good alternative to explore the reasonability of extreme scenarios and reason back to what we can expect from a change in laundry facilities provision on energy consumption for laundry purposes.

An empirical study of the behavioral response of developers and investors to the LEED rating system

Paper IV reports results related to a market based sustainability rating tool. To investigate how the design of the LEED system may influence incentives for market actors to invest and build more sustainably, the issue was approached from two ways. One was to look at the actual scoring system; how its categories and thresholds have been updated and on the resulting hypothetical re-scoring of existing certificated buildings. The other way was to look at developers' behavior when they design and construct buildings that will be certified.

A large dataset had been collected from existing LEED projects in which all the points for each individual attribute had been registered. This was used to illustrate how the scoring had been distributed in all of the projects. The two versions of the scoring systems were also compared and depending on what attributes the projects had been rewarded points for, they could get a different total scoring in the updated version.

Studying the resulting aggregate trends instead of looking at individual projects, for example by interviewing developers, gives an idea of how systematic the phenomenon might be. Recognizing that new construction projects are being assessed differently under different versions of the LEED system is in itself an important contribution. More knowledge about developers' aims for specific attributes and levels would require in-depth studies, but the results in this paper, indicating that they may be cherry-picking attributes, may serve as a basis for discussion about the design of rating system and a starting point for future studies.

4.3 Learning what matters: Explanatory approaches

Finally, questions about "what" actors do and "how" they do it have been complemented with two studies that ask more specific questions; narrowing down previous knowledge to formulate hypotheses and testing if relationships hold. In the first one, data was collected from housing firms using the results from paper I as a basis to design a web survey. In the other one, a relatively large dataset combining two independent sources was used for a research question that focuses more generally on market signals. For paper V, the most relevant research questions were "1. How are aspects of sustainability perceived and handled by market actors?", "2. How, in practice, have market actors handled sustainability related features?" and "3. Are there economic incentives for sustainability?" For paper VI, research questions 1 and 2 were also relevant but instead of research question 3, question "4. What else than economic rationality may explain sustainability ambitions?" was studied. Neither of the papers makes any strong case for causality but both logically argue why the identified relationships make sense beyond coincidence.

Who will close the energy efficiency gap? A quantitative study of what characterizes ambitious housing firms in Sweden

This study used insights from the first multiple case study described in paper I, based on which questions and affirmations were formulated for the web survey. A small number of questions were background used as information, the rest were self-assessed and self-reported experiences of how the renovation process and energy efficiency work within the firm and in Sweden is proceeding. Thus, the questions were qualitative in nature but the treatment of the data was quantitative to look for the aggregate patterns across the ideal type firms. The motivation for this method was to avoid a situation where firms focused on whether they had installed specific technological solutions or dropped out because of time-consuming questions on a detailed level, when what is really interesting was to get a general idea about the attitudes to energy efficiency among the firm types. The classification of firms as more and less ambitious contained some measure of subjectivity, which had to be weighed against the value of the results. The survey reached a larger number of housing firms than would have been possible with interviews and thus some of the results could be used to validate the results from the underlying case study and also to increase generalizability.

The impact of energy performance on single-family home selling prices in Sweden

Lastly, paper VI focuses on market signals and as such, it was natural to study aggregate data, in this case transaction data coupled with the new energy performance data. Single-family homes were studied because of the availability of data, although this naturally limits the generalizability to multi-family buildings, in particular within the rental sector. However, knowing that the market values (or doesn't value) energy performance by assigning a premium to energy efficient homes and real options in the form of recommended energy efficiency improvements is a valuable insight since single-family homes buyers have little else to take into consideration. There are less trade-offs and less split incentives within the household and between the household and the rest of the market than what is the case with the firm.

The hedonic regression is not handling experimental data so there is a risk that data suffers from some type of bias. However, recognizing that the model including the energy performance parameter seems to explain more of the variation in price than the model without a measure for energy performance still gives some insights, particularly noting that the estimated value corresponds fairly well to energy savings.

4.4 Reflections on limitations and reliability

The limitations of the research methods are well-known and discussed in each of the papers. Using a mixed methods approach, the hope has been to overcome some of the weaknesses of qualitative and quantitative methods respectively by choosing a method suitable for the specific research question and available data (Johnson & Onwuegbuzie, 2004; Creswell & Clark, 2010). Some general comments are provided here for purpose of the whole thesis and its research contribution.

Several of the studies build on interviews and the relationship between the researcher and the research subject will always lead to questions about preconceptions, objectivity and the ability to register, understand and interpret information on behalf of the researcher as well as questions about willingness and ability to share objective and relevant information on behalf of the research object. The general strategy has been to follow up and cross-check information to as large of an extent as possible. The inexperience of myself as a researcher entering the study reported in paper I made it difficult to assess the information in the first interviews, which is why more interviews were added until a consistent picture had been painted. The relatively close relations between the research team and the case firm in paper II gave reason to be cautious about the objectivity of the researchers and the complete sincerity of the case firm, which is why many types of actors from within and outside the firm were interviewed to get a triangulation of views.

As far as quantitative data are concerned, the studies in papers III, IV and VI have similar limitations; it is hard to sort out what is behind the data. The kind of considerations that have been done on behalf of investors, developers and home owners and the kind of local conditions and limitations that they have faced remain unknown. However, despite the fact that hard data may hide information, systematic patterns do tell us something, if nothing else that we should continue to investigate. In paper V, the main limitations of the study are the small sample size and the interpretation of self-reported data – how were the questions been interpreted by the respondents and how should their answers be understood. Being able to control what firms claim and find out if it is only cheap-talk is perhaps less important (since this will become evident with time) than knowing that the firms and the researcher share the same understanding so that policy makers can design the best possible tools to align interests and achieve social goals.

5 SUMMARY OF PAPERS

Paper I: "Incentives for Improving Energy Efficiency When Renovating Large-Scale Housing Estates: A Case Study of the Swedish Million Homes Programme" by Lovisa Högberg, Hans Lind and Kristina Grange.

Published in *Sustainability* (2009), Vol. 1 No. 4, pp. 1349-1365.

This paper reported the early findings from a study among Swedish housing firms who own and manage buildings from the 1960's and 1970's, the so called Million Homes Program (MHP). The aim of the study was to explore how housing firms view and handle questions related to energy efficiency and renovation in the MHP buildings. Approximately one fourth of the Swedish housing stock was constructed during the MHP, generating a renovation hump at this point of time in the building life-cycle and potentially a window of opportunity for housing firms to carry out extensive energy efficiency measures.

The study was based on semi-structured interviews with 13 municipal and 3 private housing firms in different parts of Sweden and gave an insight to the type of considerations housing firms need to deal with and in particular, that not all firms deal with similar issues in the same way.

The main contribution of this paper was to develop a typology that highlights that not all housing firms will handle energy efficiency matters in the same way. Rather, the level of ambition in terms of how much they intend to improve energy efficiency will vary depending on their main motivational driver. Four ideal types are suggested: the Strict Profit Maximizing Company (SPMC), the Little Extra Company (LEC), the Policy Led Ambitious Company (PLAC) and the Administration Led Ambitious Company (ALAC). The SPMC are mainly driven by financial gains in the short to medium run and will go about with energy efficiency in a business-as-usual manner. The LEC will be more inclined to investments in energy efficiency even in the longer run motivated for example by more generous assumptions about changes in net operating costs or the value of goodwill. The PLAC and the ALAC both have ambitious goals for energy efficiency improvements, driven by the political management or by enthusiasts within the organization. Ambitious firms motivate their efforts with internalization of external environmental costs, a very long-run perspective and sometimes manipulate calculations in ways that do not meet profitability criteria.

The conclusions of this paper are that housing firms have different drivers and depending on the context they operate in, e.g. with an active and idealistic owner or a declining market, it will be rational for the firm to act in a certain way. This is important to remember when designing policies for energy efficiency, that there is no one-fits-all solution.

Paper II: "Sustainable renovation strategy in the Swedish Million Homes Programme: A case study" by Hans Lind, Kerstin Annadotter, Folke Björk, Lovisa Högberg and Tord af Klintberg

Submitted to *Housing Policy Debate*.

This paper analyzes the renovation strategy of a housing firm in peripheral Stockholm with (social) sustainability ambitions. The majority of the firm's buildings were constructed during the Million Homes Program (MHP) era, meaning the firm needs to renovate a large share of its building portfolio within a short period of time. As noted in paper 1, the magnitude of renovations of the MHP buildings constitutes a great challenge for many housing firms and the paper thus highlights the complexity involved with decision making.

The aim of the paper was to develop a framework that could be used to assess sustainability in a renovation context and to learn about sustainable renovation by applying this framework to a specific renovation situation.

The three sustainability dimensions were operationalized to allow assessment of individual efforts and strategies. Existing building classification systems were used as a starting point for environmental sustainability, highlighting the most relevant aspects to suit the renovation context such as energy use, choice of materials and indoor environment. Social sustainability was assessed using the concept of social capital, here interpreted as the (economic) ability of households to stay after renovations, i.e. the opposite of renoviction. Economic sustainability was interpreted as renovation that does not need internal or external subsidies; that the renovations give an acceptable return on invested capital to the firm without shuffling (social) costs to the public sector.

Interviews were conducted with various representatives from the housing firm and with other stakeholders to get an extensive understanding of what an individual firm, its tenants and its owners deal with technically, economically and socially.

The main findings of this paper were that the sustainability concept needs an additional dimension – technical sustainability – to take into account the longevity and reliability of technical installations and that sustainable renovation with regards to all four dimensions is achievable but requires tradeoff since the three (four) dimensions often are in conflict.

Paper III: "Organization of Laundry Facility Types and Energy Use in Owner-Occupied Multi-Family Buildings in Sweden" by Lena Borg and Lovisa Högberg

Published in *Sustainability* (2014), Vol. 6 No. 6, pp. 3843-3860.

This study originated in the observation of a shift in developers' construction practices; in-unit laundry appliances were increasingly replacing the communal laundry rooms in owner-occupied multi-family buildings. Energy use is driven by three factors: the number of appliances, the energy performance of the appliances and user behavior. Since at least one of the factors change as a result of the shift, the aim of this paper was to document whether the shift was systematic and to explore some of the consequences it thus would have on energy use for laundry purposes.

The study combined on-site visits to document construction practices in buildings from three eras between the late 1980's and the 2000's with an online survey of ongoing projects to document current construction practices. The possible implications for energy use were explored using a numerical example that highlighted the thresholds for when one type of building practice used more energy than another type of building practice.

The main contribution of the study was to document the shift in building practices from communal laundry rooms to in-unit appliances. Looking deeper to find the rationality for this, it becomes visible that social and legal changes, e.g. demand for appliances and new building regulations, (unintentionally) may drive organizational and technological change, like when firms respond by abandoning the communal laundry room to capitalize on the new circumstances.

The results of the study indicate that despite the higher number of laundry appliances, shifting from communal to in-unit appliances does not necessarily increase energy use for laundry, depending on energy performance of the appliances and on user behavior.

The findings underline the need to reflect on old and new practices, and to see how components relate to the system in order to find an optimal outcome, e.g. in terms of minimized energy consumption.

Paper IV: "An empirical study of the behavioral response of developers and investors to the LEED rating system" by James DeLisle, Terry Grissom and Lovisa Högberg

Published in *Journal of Property Investment and Finance* (2013) Vol. 31 No. 1, pp. 10-40.

This paper presents the results from a study that investigated some possible drawbacks with environmental classification systems, in this case LEED. Environmental systems have been created as a means to overcome information asymmetry and to convey the benefits of sustainable buildings, thereby facilitating market pricing of sustainability features. In order to make the system credible and potent, it needs to be updated along with technology advances. This, however may have unintended consequences for investors, if updates imply that a certified building no longer lives up to the original certification level.

The aim of this paper was to explore the durability of any value premium resulting from a certain certification level and to investigate the behavioral response of developers and investors to the design of the LEED system.

The achieved credits for a sample of 591 projects certified under the 2005 NC2 version of the LEED certification scheme were rescaled to fit the newer NCv2009 version, in which the importance between categories had been redistributed and regional priorities had been added.

In total, 13.5 % of the projects that were classified using the NC2 version in 2005 would have had a lower rating if they would have been classified using the NCv2009 version and 4.5 % would have had a higher ranking. A total of 18% of the projects were reclassified either up or down. The results also showed that there was a tendency among developers to aim just above the breakpoint between rating levels and these projects were reclassified downwards to a higher extent as a result of the adjusted priorities. The findings indicate that it may be complicated for future investors to assess the meaning of sustainability ratings and attribute a correct value.

The results also suggest that creating new incentive structures that span many industries and types of actors is complex and that even well-planned incentive structures may backfire. In addition, the findings draw attention to the fact that although the purpose of indices may be good, as an attempt to approach sustainability holistically, the end-result may be hard to interpret and the measure may be noisy.

Paper V: "Who will close the energy efficiency gap? A quantitative study of what characterizes ambitious housing firms in Sweden" by Lovisa Högberg

Submitted to *Housing Theory and Society*

This paper builds on the results in paper 1 and in particular the findings that some housing firms have an ambitious approach to energy efficiency improvements. Despite a claimed gap between the level of energy efficiency actually reached today and the level of energy efficiency that is technically feasible and supposedly has a positive net present value, some housing firms appear to do more than expected. If we want to overcome barriers to energy efficiency, which are likely to impede improvements unequally much in different types of firms, it is important to identify the conditions that are favorable for ambitious firms.

The aim of the study was to identify factors that characterize ambitious firms and the market they operate in. Six hypotheses were formulated; ambitious firms were believed to be municipal, to be operating in markets with high and/or volatile energy prices, to be operating in strong markets, to have building portfolios in need of renovation, to be large and to have an expert employee who champions energy efficiency issues.

A web survey was sent to municipal and private housing firms who own and manage buildings from the Million Homes Program (MHP) era. 111 firms, 32 %, responded and were classified based on the typology developed in paper 1. Firms were classified as the Strict Profit Maximizing Company (SPMC), the Little Extra Company (LEC) and the Ambitious Company (AC, which is a merger between the Policy Led Ambitious Company (PLAC) and the Administration Led Ambitious Company (ALAC) in paper 1).

The results indicate support for some of the hypotheses; the probability of being ambitious increases if firms are municipally owned, have a building portfolio in need of renovation and have an employee who champions the energy efficiency issues. There were no indications that high/volatile energy prices, strong markets or firm size influence the probability of being more ambitious. The main contribution of this paper is that there are conditions that influence the level of ambition and that therefor need to be taken into account when assessing energy efficiency potential and designing policy interventions.

Paper VI: "The impact of energy performance on single-family home selling prices in Sweden" by Lovisa Högberg

Published in *Journal of European Real Estate Research* (2013) Vol. 6 No. 3, pp. 242-261.

This paper investigates if the market value of single-family homes reflects energy performance. Energy Performance Certificates (EPCs) for buildings were introduced in the European Union in the 2000's and have since become mandatory at the point of selling. EPCs overcome some of the information asymmetry between seller and buyer and signal the current energy performance as well as the potential energy performance by including individual recommendations for cost efficient energy efficiency improvements.

The aim of this paper was to establish if there is a market response to energy efficiency in single-family homes at the time of selling and if recommendations are considered a real option to improve energy efficiency.

A hedonic regression analysis was carried out using EPC and transaction data. The regressions were run using selling prices as the dependent variable and energy performance, recommended measures and other factors controlling for attributes and quality were used as the independent variables.

The results indicate that for a 1 % improvement in energy performance, there is a marginal increase in price premium of 0.44 %, which yields a capitalization rate of approximately 7 % for the average sample home. Recommended energy efficiency measures, on the other hand, do not appear to be valued as a real option; rather it is something that buyers require a discount for if included. The results indicate that it seems to be rational for home sellers to improve energy efficiency prior to selling their homes.

5.1 My contribution to the included studies

The role and contribution in the six included studies has varied, the extent to which is clarified here. In paper I, I individually collected the data, whilst analysis and writing was done in collaboration with supervisors/co-authors. The data collection, analysis and writing in paper II were done by joint forces, with my most active role taken during data collection and also as main responsible for the parts regarding social sustainability. In paper III, the original data was provided by co-author whereas research design, supplemental data collection, analysis and writing were contributed to equally. In paper IV, I performed part of the analysis and in papers V and VI I individually performed individual research design, data collection, analysis and writing with due support from supervisors.

6 CONCLUDING DISCUSSION

Sustainability in a real estate context has been interpreted broadly in this thesis, encompassing single indicators like energy efficiency and broader measures like sustainability indices or general sustainability concerns. Seen against the theoretical background of this thesis, the results support the idea that there are existing incentives in the market or provided by policy makers to which it is in the self-interest of the firm to respond sustainably. All of the studied firms in all of the papers will respond to price signals in the market and they will also act according to the existing regulatory framework such as building codes to avoid punishment. Some of the firms in paper I are driven exclusively by profitability and the adoption of energy efficiency measures then depend only on material incentives. In paper III, the change in construction practices for laundry facilities was not carried out because of some specific environmental concern, which luckily didn't turn out to have the strong impact on energy consumption as feared in the initial hypothesis. The investors and developers in paper IV are driven in large part by perceived profitability, and sustainability rating tools thus need to be carefully designed so that market actors don't lose confidence in them. Finally, the results in paper VI indicate that markets do to some extent acknowledge and signal the value of sustainability in terms of energy efficiency.

The results above support neoclassic economic theory and suggest that if the current market outcome is not sustainable (enough), then incentives have to be provided by government (or other long-term actors such as industry networks) for us to arrive at a socially (more) optimal solution. However, the results of several of the studies indicate that there are also firms who act in a sustainable manner and who engage in prosocial behavior for other reasons than (short-term) profitability. These firms are motivated by other drivers than material (economic) self-interest. Image concerns may help explain why consumers and firms demand sustainable real estate and image concerns may also explain why actors in the real estate industry voluntarily strive for sustainability levels beyond regulation and short-term profitability. Some of the firms in paper I and V express how they want to contribute to a more sustainable development in an altruistic sense whereas other firms care about image and appear to use sustainability for marketing purposes. The firm in paper II changed their renovation practices partly after protests and wants to be seen as the tenants' ally. In paper II, it is also demonstrated how firms need to comply with many objectives. It reports a firm strategy which, even if not profit maximizing, still gives a satisficing level of sustainability in all of the three dimensions, including the economic dimension. The case thus manifests a satisficing behavior but in which image concerns are clearly important to what renovation strategy they choose. Also, the firms in paper IV who choose to adopt sustainability rating tools clearly have a desire for their sustainability efforts to be noticed (compared to simply carrying out the sustainable construction without adopting the sustainability rating) in addition to the perceived material benefits.

It is also worthwhile considering the circumstances in markets that aggravate accomplishing sustainable real estate; split incentives, asymmetric information and transaction costs. Starting with split incentives, from papers I, II and V, the type of firm behavior, sustainable or not, may or may not be in the interest of the whole firm (represented by its owners). What is worse, however, is that different actors will have different interests in a building over the course of time. This means that the incentives of the actors may be poorly aligned, particularly if they don't have the same time horizon.

The market actors studied in this thesis deal with sustainability in different ways. Developers appear to be more market driven and respond to short-term economic incentives to a larger extent than housing firms. One possible explanation for this is that developers' time perspective in relation to real estate is relatively short and there is not (yet?) a strong enough willingness to pay for (long-term) sustainability features. In this sense, the circle of blame concept is highly relevant.

Housing firms, in turn, seem to be considering sustainability to a higher extent in their management of buildings although not all of them in an equal way or equally much. Again, time perspective is a relevant dimension and differs between housing firms; firms who have adopted a longer time perspective seem to care more about sustainability related features, including tenant considerations.

In order to further sustainable real estate and for all market actors, including those driven mainly by material incentives, to be able to benefit from sustainability features, information needs to be less asymmetric and transaction costs need to be lowered. Energy performance certificates and LEED certification are two examples that reduce the asymmetry by making sustainability related information available in the market. It is also a way of signaling the intention and ambition of the firm, if the firm wants to convey an image of itself as being prosocial. Standardized certifications are also one example of measures that reduce transaction costs by having a third party verify that the actions are sustainable, to those consumers who wish to pay for it. Taking these measures will improve the situation in the market and create better conditions for a situation of virtuous feedback loops that reinforce market signals.

Returning to the questions posed in the introduction of this thesis, what can be learned from the results of the papers?

1. How are aspects of sustainability perceived and handled by market actors?
2. How, in practice, have developers handled sustainability related features?
3. Are there economic incentives for sustainability?
4. What else than economic rationality may explain sustainability ambitions?

To answer the first question, aspects of sustainability, which in this thesis has been interpreted as anything from energy efficiency to ability to stay in the dwelling after renovation to sustainable value premiums from building certification, have been perceived and handled very differently by different market actors. This depends on different drivers for sustainability as well as different circumstances in the market. When firms are only driven by material incentives, it will be straightforward to analyze how sustainably they will act, provided there are clear price signals and/or policy incentives that signal the importance of each or all of the sustainability dimensions. When firms are driven by other motives (as well), it will be more complicated, since there is a risk of crowding out extrinsic and intrinsic motivation to act sustainably. In the single-case study of paper II, the firm in question was not adopting the seemingly most profitable strategy but chose to balance the three sustainability dimensions when renovating.

To answer the second question, it can be noted that some firms have come a long way in consciously handling matters of sustainability, in environmental as well as social and economic dimensions. Papers I and II gave examples of specific efforts they have undertaken and thus an understanding of what individual housing firms deal with technically, economically and socially. The results made it clear that firms' endeavors take place in specific contexts and the different drivers and different approaches indicate that there is no one-fits-all solution to influence housing firms to act more sustainably. However, housing firms may and often do act sustainably and the right conditions may further advance this behavior.

Among the housing firms in the multiple-case study in paper I, at least rhetorically, some firms have made sustainability a marketing issue, others have adopted a more altruistic and socially responsible approach, not necessarily compatible with profit maximization, and yet others do nothing in particular do achieve sustainability in other dimensions than the economic. Some firms, as reported in paper IV, voluntarily adopt environmental assessment schemes, and among those who do, many of them appear to have aimed to get most bang for the buck in term of sustainability rating rather than having aimed for environmentally sustainable. This may still be more ambitious than those who don't adopt environmental rating schemes at all, in which case the environmental dimension and to some degree the social dimension has been satisfied to a higher extent. It is not clear whether sustainability issues were considered when developers studied in paper III shifted their building practices from communal to in-unit laundry facilities, but the results underline the importance of seeing the bigger picture in terms of regulation, costs, consumption and distribution of responsibility.

Regarding research question 3, papers IV and VI point to the more economic drivers of sustainability and at the same time again highlight the complexity that may be involved when sustainability is to be priced. Comparing the two papers, it seems that the more holistic the sustainability assessment approach, like environmental classification schemes attempt with their indices, the more difficult it is to interpret and value sustainability over time. Keeping it simple by only assessing one aspect (for example energy performance) is by no means a perfect way of approaching sustainability assessment but may increase clarity and more easily signal information to the market. This may be particularly true when information and value need to be signaled not only within sectors but also across sectors to actors who often have different motivational drivers and goals.

Finally, research question 4 has been answered already but there are clear indications in papers I, II, IV and V that not only material incentives matter. Image concerns and altruism can make individuals behave in a sustainable way, which when translated into the firm may be with or without the approval of the owner.

The geographical staticness of buildings implies that real estate actors will be subject to some policy incentives and producers of space, particularly those dealing with existing buildings, will have to optimize production within certain limits. This means that production will be impacted to some extent by local jurisdiction, and that local market conditions will play an important role in what demand the firm meets and what incentives they have. Furthermore, the geographical conditions influence operation and maintenance needs as well as environmental needs and conditions.

Furthermore, buildings are durable, and may over the course of their lifecycle be subject to many interests. The developer, the owner, the tenants and the local government are but a few of the potential stakeholders and the real estate may be subject to transactions between these stakeholders.

Because of the complexity of buildings, the market will be characterized by a high degree of asymmetric information. Developers will know more about the buildings than the majority of the buyers, and buyers may value certain aspects of a building but the valuation of a certain aspect will easily disappear in the noise when other aspects are being valued simultaneously.

From the studies, it is clear that there is a large variation in how sustainability related features have been handled in practice. There are material incentives for actors to consider sustainability, at least to a certain extent. Consumers in the single-family homes market seem to be willing to pay a premium for energy performance and although this transaction is less complicated than that between for example landlords and tenants, this should have implications in other markets as well. If it doesn't, it is an indication that there are barriers to efficiency within those markets.

In summary, it is of great importance to analyze incentives in detail considering not only the time horizon of relevant actors but also the scale on which they operate. Recognizing the limits of actors' responsibilities and interests in each of these dimensions is crucial for policy design and the continued sustainable construction and management of the built environment.

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Article

Incentives for Improving Energy Efficiency When Renovating Large-Scale Housing Estates: A Case Study of the Swedish Million Homes Programme

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Abstract: Sweden has adopted ambitious energy savings objectives for buildings, but at the current rate of energy efficiency investments the objectives are unlikely to be reached. In this article we report the early findings of how real estate owners reason and act in energy efficiency investment decisions. Based on the results from interviews with the real estate companies, the companies have been divided into four ideal types that illuminate the differences in energy efficiency ambition and strategies; the Strict Profit Maximizing Company, the Little Extra Company, the Policy Led Ambitious Company and the Administration Led Ambitious Company. The different strategies will determine how the companies respond to incentives to invest in energy efficiency, and affect the overall result in the energy efficiency work. The ideal types hence are important to have in mind when designing policies to increase energy efficiency.

Keywords: energy efficiency in buildings; sustainable renovation; incentives for energy efficiency; ideal types

1. Introduction

Sweden built more than one million housing units between 1962 and 1975, and now it is time to renovate most of this stock. A number of renovation projects have been carried out and there seems to have been very large differences in how much focus there has been on energy efficiency in these projects. Given the government's ambitious energy savings goals, and that it could be argued that there is a "window of opportunity" when large investments are planned anyway, so it is worrying that more is not being done. In earlier studies [1,2] it is claimed that there are a large number of profitable energy savings investments that the real estate companies do not carry out. The general purpose of the research project that is reported here is to understand why this is the case and what can be done to increase energy-saving investments in the housing stock that is in need of renovation.

Our starting point was that it is important to understand why the firms do what they do, and therefore interviews were initially made with a selection of housing companies. What is reported in this paper is to a large extent "work-in-progress". The strategy followed here is that from the interviews we try to construct a number of "ideal-types" which describe how different types of firms act in relation to energy-saving investments. These ideal types can help us understand better the action of the companies and also make it possible to, in general terms, predict how they will respond to different policy measures.

The interviews are also used to develop a more precise set of hypotheses about why not more is done, and what can be done to influence the decisions, and this will be investigated more in detail in later stages of the project.

The structure of the paper is as follows. The opening sections give some background information, starting with the Swedish policies in Section 2, and describing the part of the housing stock in question, known as the Million Homes Programme, in Section 3. Section 4 describes the method and data/interview material used. Section 5 reports the results from the interviews and the analysis based on the ideal types. Section 6 concludes with a discussion of the results found and their implications.

2. Swedish Energy Policies

To put the question of energy efficiency in buildings (in Sweden) into context, former and current Swedish energy policies, as well as the current energy consumption situation will be presented here.

2.1. Earlier Energy Efficiency Programmes

Public action programmes for energy economy have been an important element in Swedish energy efficiency policy since the 1970s [3]. The most important early policy measures, during the 1970s and 1980s, were investment subsidies and information campaigns. During the 1990s two programmes were introduced. The energy policy decision of 1991 included support for procurement and introduction of energy efficient technology, demonstration of energy efficient technology in dwellings and premises, grants to pilot plants, and renewed support to information on energy efficiency. In the energy policy decision of 1997, the so called short term programme, additional measures were proposed, among others measures for decreasing electricity consumption.

In the 1990s an initiative was taken for an action programme for energy efficiency, focusing specifically on the Million Homes Programme [4]. This never led to any political decision; however it did lead the former Prime Minister Göran Persson to the introduction of the somewhat visionary term *People's New Green Home*.

While energy policies in the 1970s and 1980s primarily aimed to reduce energy consumption in order to lessen the oil dependence (and following a referendum in 1980 also to replace nuclear power energy), today's energy policies predominantly have climate effect reduction in focus [5-7].

The first climate policy was adopted in 1988. The aim was to stabilize CO_2 emissions at that time's level, but this objective was later expanded to include all greenhouse gas emissions in all sectors, and in 1993 a national climate strategy was adopted. The strategy was in line with the United Nations Framework Convention on Climate Change (UNFCCC) and aimed at stabilization of 1990's level no later than 2000, followed by reduction in emissions. Sweden has signed the Kyoto protocol [8].

2.2. Current Energy Efficiency Programmes and Objectives

Today's energy efficiency policies are mainly based on guiding principles that were adopted in the beginning of the millennium, however, an important difference is that new policy objectives have been added [3].

Ever since the national climate strategy was adopted, the Swedish energy and climate policies have been closely tied together and strongly influenced by the EU policies, although many times more ambitious. One important issue has been the EU Directive 2006/32/EC on energy end-use efficiency and energy services (ESD), which requires all member states to draw up national action plans for energy efficiency. Energy efficiency is seen as a means to combat climate change, together with a higher degree of renewable energy sources. These two areas, along with a higher degree of renewable energy in the transport sector, are the plans of action to reach the overarching climate goal to reduce climate emissions by 40 percent [3]. Altogether this contributes to a secure and sustainable energy distribution.

The Swedish objectives are quantified as a 40 percent reduction in greenhouse gas emissions (in the non-trading sector), a 50 percent share of renewable energy, a 20 percent more efficient energy usage and a 10 percent share of renewable energy in the transport sector. These objectives are to be reached in 2020 and relate to the level of 1990. The ambition is that the energy savings will be reached through cost-effective measures, given the energy efficiency gap that has been identified [3].

The EU climate and energy goals, summarized in 20-20-20, imply a 20 percent reduction in greenhouse gas emissions (compared to 1990), and at least a 20 percent share of renewable energy sources by 2020. The EU also has goals for energy consumption in buildings, aiming at a 20 percent reduction by 2020 and at 50 percent improved efficiency by 2050.

In addition Sweden has 16 national, non-legally binding, environmental objectives that all strive toward a sustainable development, with the aim to solve the major environmental problems by 2020. The implementation of the objectives is divided between the national, regional and local level. The environmental objectives that directly relate to energy efficiency are a *Reduced Climate Impact*, *Clean Air*, *Natural Acidification Only* and *a Good Built Environment* [9].

2.3. The Public Sector as a Forerunner

A founding principle in the ESD is that the public, *i.e.*, the national, regional and local governments, should have a key role and be forerunners in the energy efficiency field.

However, the Swedish government has decided that the government alone shall take responsibility for being an example to other actors. Regional and local governments are instead offered the possibility to sign voluntary agreements on energy efficiency. Whether the municipal housing companies adopt a role as a forerunner or not has thus primarily become a local political issue, stated in the municipalities' steering directives to the Housing Company. This question is further complicated by the ongoing EU investigation concerning whether municipal housing companies should act on the same premises as private companies, or if certain exceptions for non-profitable housing companies should be adopted [10].

2.4. Energy Consumption in Sweden

In 2007 the total energy usage in Sweden, with a population of 9 million, amounted to 624 TWh, out of which 404 TWh was for end use consumption. The share of renewable energy was 43.9 percent, which was contributed mainly by electricity production through hydroelectric power. Not including district heating originating from renewable waste heat or renewable electricity in electric heating furnace, the total renewable district heating production was 25 TWh in 2006. The buildings and services sector consumed 35 percent, 143 TWh, of the total end use consumption, out of which 60 percent is used for heating and hot water. The sector consumed approximately 70 TWh of electricity, mainly for operating electricity for premises [11].

A total of 27.2 TWh of energy was used in 2007 for heating and hot water in multi-dwelling buildings (with a total of 180 million heated square meters in 2.4 million apartments). The predominant source of energy for this purpose in Sweden is district heating, by which 82 percent of the total area in multi-dwelling buildings were heated in 2007. This corresponds to an average usage of 151 kWh per square meter. During the same year oil heated approximately 1 percent of the multi-dwelling area. The total water consumption was 272 millions of cubic meters [12]. In most cities in Sweden the energy company is owned by the municipality and run on a break even principle.

3. The Million Homes Programme

Energy efficiency in existing buildings is a general problem, but has come even more into focus in Sweden given the ageing housing stock, of which a large part was built during the 1960s and 1970s, and hence is anticipated to be in need of extensive renovations within the next 5 to 10 years.

3.1. Background

The Million Homes Programme was the political decision to build one million dwellings to cope with the housing shortage and in many cases low housing standard of the 1960's. The decision was taken by the Swedish Parliament in 1965 and involved governmental subsidies to stimulate construction. Because of the pressing time schedule and shortage of labor an industrial approach was adopted where pre-fabricated elements were used to a large extent. The goal was reached in 1974, when 1,006,000 dwellings of varying type had been built, of which two thirds were apartments in multi-dwelling units [13]. Another term, the Record Years, is sometimes mentioned in relation to the Million Homes Programme. This period dates back to 1961, and taken together during the period, 1961–1975 approximately 1.4 million dwellings were built of which two thirds were in large-scale housing estates. In this article no explicit distinction will be made between the buildings dating from the two periods, as many of the questions are applicable to the older part of the building stock as well.

The public owners, *i.e.*, municipal housing companies, took part to an increasing extent in building the Million Homes Programme and contributed with the construction of approximately 60 percent of the multifamily dwellings [13]. The municipal housing companies in Sweden build for a large section of the population and it is not social housing in the traditional sense. Out of the 650,000 multi-family apartments still left of the Million Homes Programme the municipal housing companies own almost 50 percent. However, it would be wrong to assume the same conditions for all public or all private owners respectively. In terms of size and economic strength there is as much variation between the public companies as it is between the private companies.

Both public and private owners operate under rent regulation. Rent is set following negotiations between the tenants' association and the municipal housing company, and the private companies have set their rent at the same level as in similar publicly owned and managed dwellings in the same area. Rent increases, except those reflecting general price changes, can only come about if a renovation increases the standard of the apartment but normally not because of energy efficiency measures. The vast majority pay an inclusive rent with respect to heating and hot water, but normally not with respect to electricity.

3.2. The Buildings' Condition Today

As it is now 40–45 years since the Million Homes Programme was built, the buildings' installations are now approaching the end of their technical life-length. Primarily this means that the main water and sewage pipes are in such bad condition that there is a high risk for damage by leakage. Furthermore the ventilation and electricity systems can be in need of replacement, all to maintain the living standard for the residents and the value of the buildings.

Apart from many installations being plain old, the Million Homes Programme in many cases suffers from additional difficulties typical for that period's buildings. New and untested construction techniques and materials as well as a too fast and sloppy work performance have led to other damages than those related to normal aging.

Many of the buildings have had problems with damaged balconies, facades and roofs, most often due to faulty techniques and materials. In addition the buildings were constructed before the higher demands on air tightness and insulation were introduced after the oil crisis, and hence heat losses can be substantial [14]. At the time of construction thermal bridges were not included in any requirements on energy economy, and as a result thermal bridges are frequent where e.g., balconies or wall elements are connected to the building envelope. The ventilation system is commonly based on mechanical exhaust air with no heat recovery, or on natural ventilation. Taken together energy consumption for heating in buildings from the Record Years is on average 170 kWh per square meter and year, but can exceed 200 kWh for heating [15]. This can be compared to the current building regulations where the requirements are 110, 130 and 150 kWh, depending on the climate zone that the building is located in [16]. A very small part of this building stock has been demolished and there are currently no plans for major demolitions and redevelopment, even though there are some controversies about this.

3.3. Possible Energy Efficiency Measures in Existing Buildings

Given the fact that buildings have been pointed out as a sector with great potential for energy savings, the upcoming renovations of the Million Homes Programme are seen as a chance to undertake extensive energy efficiency measures. Many claim that the "window of opportunity" for renovation is now open and cannot be missed, since it is likely that it will take a long time until further renovation and maintaining work is performed.

Measures that can improve energy efficiency in a building can be divided into three categories. *First* there are the measures that aim to reduce heat leakage from the building envelope. This can be done by sealing leaks in the walls or around the windows, by replacing windows, by attending to thermal bridges, and by adding extra insulation to outer walls, basement floors and roofs. *Second* there are the measures that *recover energy*, which can be done by installing balanced ventilation with heat recovery, or by installing exhaust air heat pump or waste water recovery. *Thirdly* there are the measures that *limit the energy distribution*, such as adjusting temperatures, optimization of operating installations and installing more energy efficient equipment. Individual metering is another plausible measure but this aims to affect behavior so that energy isn´t used at all, *i.e.*, is saved, rather than to use energy more effectively [15].

The measures in the third category are minor in comparison and often very cost effective. The measures in the first and second category can be minor or extensive, depending on the conditions of the buildings. Some buildings are well suited for e.g., installing heat recovery while in others there is a need to reconstruct much of the ventilation shafts to achieve this, and the same is true for insulation which easily can be added to some buildings while other need extensive modification. It is therefore hard to say generally that some measures of these two categories are cost effective and others are not. However, regardless of the initial conditions the measures are quite extensive and require planning. Also, the investments in the first category generally have a longer life-length than most of the installations from the second category.

4. Method and Data

This section starts by describing the method of using ideal types, and continues with a presentation of the interviews.

4.1. Ideal Types

Ideal types are used to extract and highlight the most important features of a phenomenon. The concept of ideal types was developed by the sociologist Max Weber, and is commonly adopted in economics, e.g., the concept of the perfect market. The researcher constructs the ideal type by accentuating one or more points, and grouping concrete individual phenomena into an analytical construct. The idea is that one can learn something about the world by constructing a rational ideal type and comparing it with reality. Hence, an ideal type is neither what the world is, nor what it should be, but rather what the world would be like if it operated according to a certain simplified mechanism [17,18].

The motive for using ideal types as an analytic framework is the differences and similarities between the companies that have become apparent in the interviews. The similarities are not big enough to permit an overall generalisation for all of the real estate companies' motives and behaviour, but neither are the differences big enough to claim that nothing can be predicted about the behaviour of one company from looking at the behaviour of another.

Depending on some key factors relevant to energy efficiency and investment decisions the companies have been grouped into categories, which help illuminating the important differences in this context. These involves factors like how extensive are the energy efficiency measures undertaken, at what stage in the process are the questions taken into account, who drives the questions, length of payback time or how certain are the estimated profits. A more detailed description of the classification can be found in appendix. The ideal types simplify what is complex and permit the companies anonymity. Each real estate company may not have its exact counterpart in an ideal type, but each company can be compared to the ideal types to see which ideal type it resembles the most. By showing the variance and width between the ideal types it can be showed that there are different types of real estate companies, and after adding knowledge about how common the different types are, the ideal types can be used to predict and explain the behaviour of the actual real estate companies.

Following the differences in attitudes and how decisions are made, the companies will also respond differently to (different) political measures to increase energy efficiency. Hence, at a later stage the ideal types can be used to design policy measures more effectively in order to reach a higher level of energy efficiency in buildings.

4.2. Interviews

During the period from April through September of 2009 representatives of sixteen real estate companies agreed to meet to give their view on energy efficiency and renovation of the Million Homes Programme. The purpose of the interviews was to get a broad view of how different kinds of real estate owners reason and act regarding these questions. A longer run purpose was for the interviews to serve as a basis for further questions and hypothesis testing in a future questionnaire to a larger sample of companies. The meetings were a form of semi-structured interviews with a pre-formulated questionnaire, where some questions were discussed only with some of the companies when it was of particular interest in that case, and other questions were added to the questionnaire along the way as experience and knowledge grew. The basic structure of the questionnaire can be found in appendix.

The interviews have been supplemented with information such as instructions from the board of directors and policy documents in order to construct the ideal types.

4.3. The Companies

The companies vary in size and range from approximately 3,000 through 34,000 apartments. The real estate companies are active in different parts of Sweden but are not geographically, nor size-wise representative for Sweden as a whole. As the interviews were made as part of an orientation phase the companies were only partly chosen strategically. They were primarily located in the central or southern part of Sweden, which among others include the largest Swedish public companies. The decision to focus on middle sized and large companies was seen as a screening criterion at this stage, in order to include as large part of the Million Homes Programme stock as possible. The chosen companies' respective share of Million Homes Programme buildings also differ, but the company whose absolute number of Million Homes Programme apartments was the smallest still had a share corresponding to approximately 20 percent of their apartment stock. This means that the question of the Million Homes Programme buildings is a major issue for all of these companies within the next 10 years. Public companies were matched with a small number of private companies to look for indications of different strategies for public and private companies. Out of the sixteen companies thirteen have public and three have private owners. Since there are Swedish examples of extensive sustainable renovation in the Million Homes Programme, there was an impression beforehand that there are ambitious and not ambitious companies, both of which were intended to be covered in the interviews.

Table 1. Interviewed real estate companies, type of ownership and size.

Company	Public/private	Size
A	Public	Small
B	Public	Large
C	Private	Small
D	Public	Large
E	Public	Large
F	Public	Large
G	Public	Small
H	Public	Large
I	Public	Small
J	Private	Small
K	Public	Large
L	Public	Large
M	Public	Small
N	Public	Small
O	Private	Small
P	Public	Large

The companies have been represented by experts, strategists, coordinators and controllers in the energy/environment field, by project leaders, heads of business units such as Residential Buildings, Technique or Environment, and in one case by the Managing Director. All of the real estate companies, except for one, have some sort of expressed objective to reduce energy consumption, but all were of course aware of the questions of energy efficiency. The companies represented are briefly presented in Table 1, and in this table the limit between large and small was drawn at 15,000 apartments. This limit can possibly be further refined to include middle sized companies when the sample grows bigger. One of the companies included among the private (Company O) is owned by a pension fund.

5. Analysis: Ideal Types

This section will present the results from the interviews that were held with real estate companies in order to get a better understanding of how they reason and act regarding energy efficiency measures in existing buildings. The results from the interviews have led to the classification of real estate companies into four ideal types, which are presented below. They are ranked according to level of ambition in relation to energy-efficiency measures.

5.1. The Strict Profit Maximizing Company (SPMC)

The strict profit maximizing real estate owner is risk averse and undertakes only those energy efficiency measures that are strictly profitable in the short run to medium run. For this kind of company an implemented energy related project is one with higher expected returns than that of a competing project, and the profitability has to be unquestionable in the profit estimates.

A typical approach is to talk about *saving*, *i.e.*, not using, energy rather than making the actual energy use more efficient. One example would be to turn off the lights (e.g., by using timers) as opposed to changing the lights for more efficient ones, however, both of those approaches are usually part of the energy efficiency work of any real estate company.

Common energy saving measures for the SPMC are found in the third category of Section 3.3, and include adjusting the temperature in the apartments or the staircases, changing the light bulbs for low energy lights or changing equipment in need of replacement for more energy efficient one (which is not necessarily a choice based on energy awareness). These are measures that don ́t require a lot of investment cost or other resources, but that show an almost immediate pay-off, both in terms of energy consumption and operating costs. More extensive energy efficiency measures are possible, but must be profitable in terms of significantly lower operating costs (or give a clear profit in terms of goodwill) to cover the investment cost in maybe five years.

Out of the sixteen interviewed firms four can be categorized into this category. It would be intuitive to sort all the private companies into this category but only the two smaller of them, companies C and J, are strict profit maximizing in the sense defined here. Two large, municipal housing companies, B and E, are also close to this type. Companies B and E don ́t necessarily allow a longer payoff time, but may do so in specific cases and hence can be considered profit maximizing in the medium run.

5.2. The Little Extra Company (LEC)

Some companies do a little extra above the strictly profitable limit, to show environmental responsibility or because they value energy efficiency higher than the profit maximizing firm does (based on other assumptions about the net operation costs or the value of goodwill). This implies the cost estimates tend to be a little more optimistic in favor of energy efficiency measures, but it is not seen as a tradeoff between energy efficiency and economic goals. Although not always clearly defined, the LEC have got objectives concerning energy efficiency, but these objectives are not given first priority.

The LEC will do all those profitable investments in energy savings that the SPMC does, but also make allowances for energy efficiency measures in e.g., renovation calculations. This type of company will not go through with an investment that implies a loss in order to reduce energy consumption, but is willing to lower demands on return and is more likely to choose an energy efficient product when facing competing alternatives of different energy standard, even if there is no detailed calculation that shows that this is more profitable.

Common strategies for the LEC is to choose the energy efficient alternative when the product has reached the end of its life length and needs replacement either way, or to advance measures that were not yet due, in order to improve energy efficiency. This type of company is also more open to "package solutions" to finance investments in energy efficiency, *i.e.*, a very profitable measure finances the energy savings brought about by other less (/not) profitable measures. By seeing a number of measures as an energy efficiency package, the package as a whole can be profitable even if some of the individual measures need not to be (or is to a less extent).

Four out of the sixteen companies have been identified as belonging to this category. One of these, company O, is a small, private company, but its owner structure may allow or encourage it to undertake measures to improve energy efficiency that are possibly profitable only in the longer run. The other three companies, F, H and P are large, municipal housing companies.

5.3. The Policy Led Ambitious Company (PLAC)

In this type of company the official energy efficiency goals are ambitious and come, to a large extent, in the form of owners' directives or the like. Energy efficiency has been given high priority and is seen as a greater good, or it is seen as something that is necessary in the long run and might as well be undertaken now. Another possibility is that the owners through energy efficient renovation want to fulfill some other goal (e.g., to combat unemployment or social decline).

The PLAC undertakes the profitable measures and is open to package solutions, but since the instruction to give priority to energy efficiency comes from the owners, this company also has a greater freedom to undertake measures that cannot be shown to be profitable. Profitability is however the ideal and this kind of company may well justify an economic loss by arguing that it internalizes the damages of greenhouse gas emissions, and the profit estimates are "manipulated" to show a profitable investment where the company wants to see it, e.g., by assuming high future energy prices.

The PLAC will consider energy efficiency measures from all the three categories, but since decisions are influenced by (company) politics there may be a difference in where in the planning process the measures are first considered. In the "worst case scenario" owner directives are given late in the process, hence increasing the risk that costs will be higher because of ad hoc solutions, however, this is not necessarily so for all the PLACs.

Four public companies have been sorted into this category. Three, D, K and L, are large and one, N, is small. These companies have got instructions to undertake energy efficiency measures, preferably in the renovation phase, and sometimes with an expressed permission to ignore profitability. This is not to say that energy efficiency work would not have happened without the initiative taken by the owners, but under the PLAC conditions no "organizational fight" is needed, and the employees only have to act upon the instructions given.

5.4. The Administration Led Ambitious Company (ALAC)

The Administration Led Ambitious Company has ambitious energy strivings but these arise mainly from the employees in the company, most often found in the managerial body. As with the PLAC economic profitability is not the obvious objective, but it may be harder to gain acceptance for expensive measures. Even if the owners are supportive of the overall ambition, they are not who initiated the ambitious energy efficiency strategy, and there might therefore be more conflicts within the managerial group in this case.

The ALAC undertakes the same measures as the PLAC, but since the ideas (may) have been present in the organization a longer time, they may also have had the time to be integrated properly in the renovation planning process, and therefore the risk of ad hoc solutions is smaller.

As noted, the ALAC will undertake measures from all three categories, and this will be done in a holistic way, although pilot projects are commonly used to start the process, to reduce the risk and to take advantage of the learning process.

The four small, public companies A, G, I and M all fit into this category. The smallness of the company may give the necessary conditions for employees to strongly influence the decision making process, through the work of individual enthusiasts.

5.5. Overview of Ideal Types

To get a better overview the companies are presented according to ideal type in Table 2. The Strict Profit Maximizing Companies are a mix of public, private, small and large companies, whereas the Little Extra Company, the Policy Led Ambitious Company and the Administration Led Ambitious Company are somewhat more homogeneous categories.

Table 2. Real estate companies sorted by ideal type.

SPMC	**LEC**	**PLAC**	**ALAC**
B (public, large)	F (public, large)	D (public, large)	A (public, small)
C (private, small)	H (public, large)	K (public, large)	G (public, small)
E (public, large)	O (private, small) [vii]	L (public, large)	I (public, small)
J (private, small)	P (public, large)	N (public, small)	M (public, small)

6. Conclusions and Discussion about Future Research

6.1. Conclusions

Given the results from the interviews we have seen that there is a variety in real estate companies' approaches to energy efficiency investments, which implies that we cannot expect a common response from them—not in the current situation, nor given possible future policy measures.

What drives companies to adopt one strategy rather than another can depend on a number of factors, a few of these have already been touched upon above. For example, a real estate company that has a strong economic position and gets instructions from the owners to reduce energy consumption will become a PLAC and energy consumption will be reduced. On the other hand, a company that goes through hard times with falling demand is more likely not to make big investments in energy efficiency, and to become a SPMC by necessity. Another factor influencing on the energy strategy adopted is related to the building stock in question. A company that has a large share of the building stock from this period, a share that is in a poor state of repair, may not afford to do anything more than what is strictly profitable, while a company that has a smaller share of this type of housing might afford to do a little extra and become a LEC-company.

What are the prospects of reaching the energy efficiency objectives, given the types of companies identified in the study? The SPMCs will not undertake extensive energy efficiency measures unless the investments are clearly profitable in a rather short term. This means that this category of companies, that already does little, will be marginally affected by most policy measures. Unless very generous subsidies are given, the investments will probably not become profitable enough for this type of company.

The LECs will continue doing marginal extra measures, and this group may be more affected by policy intervention. Many countries have introduced such subsidies (see e.g., Amstalden *et al.* 2007 that describe the situation in Switzerland [19]), but a risk is that companies postpone measures if they anticipate that subsidies are coming.

The ALACs and the PLACs are already on their way to achieving the ambitious objectives within their own stocks. However, a risk with the PLACs is the high dependence on policy decisions, meaning a shift in government may change the picture rapidly. If an energy aware political majority loses power, energy efficiency work may be cancelled. On the other hand, if an energy aware majority comes into power large investments may be done that aren ́t well thought through, and this can lead to set-backs. Hence, the PLAC is an unstable structure that should not be relied upon too heavily in the energy efficiency work. A similar type of instability can be expected in the ALAC-company, as changes in the administrative staff can lead to policy changes.

The overall result in succeeding to reach the energy savings objectives will then depend on how many companies undertake energy efficiency measures, and on how much these companies do. With today's rate of investment energy efficiency objectives will not be met and at least two of the ideal types will not be more than marginally affected by indirect policy intervention. A more direct intervention might thus be called for, but the design of this should take into account how the real estate market is structured and on what the existing incentives and obstacles are.

6.2. Future Research Issues

One important remaining issue is to find out how large share of the companies are close to each of the ideal types. As mentioned above we plan a questionnaire to collect information about this. The research carried out so far also raises a number of further issues:

How many measures are "really" profitable? The result so far indicate that the belief that there is a large number of measures that are profitable, but not carried out might be mistaken. The impression from the interviews is that the firms that make large-scale energy related investments when they renovate cannot show that this is profitable and often add other more broad arguments—in terms of pilot studies and that they want to show that they are willing to contribute to the national goals about energy saving. If it turns out that many measures are not profitable, and if the SPMCs and LECs represents the majority of the Swedish real estate companies, it is either necessary with some kind of subsidy if the government want the companies to do more, or that energy taxes are raised. More direct regulations might also be needed.

How is profitability really calculated? Calculating profitability of an investment is not easy and a number of assumptions must be made. Perhaps the companies are making mistaken assumptions and therefore come to the conclusion that measures are not profitable? There are three points where such "mistakes" are possible, and that is assumptions about costs, revenue (energy saving and energy prices) and the discount rate. An example could be that the firms are using their traditional discount rates which might be around 5–8 percent. During the last ten years the interest rate has however on average been clearly below that, and the aggressive use of interest rate reductions by Central Banks in recession, might lead to lower average interest rate of the business cycle, so maybe a "correct" discount rate would be 3–5 percent. Such a change could to a large degree affect the profitability of long run investments.

How can policy affect firms that are not profit-maximizers? If the companies, in line with the theory put forward by Herbert Simon, are "satisficers" and currently are making a reasonable profit they might not be interested in doing things to increase profits more. The Swedish property owners' association has argued that many small property owners do not even do the simplest and most profitable things, like adjusting heating and ventilation equipment [20]. In our sample no such companies were found but this could be seen as a fifth ideal type. One way to affect the "satisficing" firms could be to give information about what can be done, and all Swedish properties must now have an "energy declaration" that should be posted in the hallway. This declaration not only describes the current energy status of the building but should also list measures that (easily) could reduce the energy consumption. As it might not "look good" if the company does not carry out these measures and some environmentally aware tenants might complain if this is not done, it might actually affect the "lazier" satisficing companies. The Swedish Property Federation is discussing a campaign focusing on these owners where the basic message should be how simple, how cheap and how profitable these measures are—but also that everyone has to contribute if the national goals should be reached!

Are measures affected by "perverse" incentive structure (split incentives)? This issue has come up during some of the interviews and concerns:

Cost-based rents: The Swedish municipal housing companies' rents are determined by negotiation with the local tenants' union. These negotiations often start from how costs develop in the firm. If energy costs are falling, because of energy reducing investments this might lead to a demand for reduction in rents, or at least a smaller increase. In this way the profit for the firm is reduced.

Individual metering: If the tenant directly pays at least part of the energy cost, and the landlord makes an investment, part of the gain would go to the tenant in the form of reduced costs, leaving less profit for the landlord.

The tariff structure of the energy company: In most cities in Sweden the housing stock is heated through district heating, and the energy company is owned by the municipality and run on a break even principle. As earlier described district heating is most common in Sweden for heating the housing stock. The energy companies' tariff is sometimes constructed in such a way that there is a large fixed part that does not change with energy consumption, and sometimes when their sales go down because of energy savings they increase their tariffs to cover the total cost. All this means that the final reduction in cost for the housing company that reduces their energy consumption might be rather low, lower than the "actual cost" saved. Of course, if the true short run saving in costs is low, then there is no perverse incentive. There are e.g., cases where heating comes from excess heat from nearby plants and where the true cost reduction actually is small.

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Appendix A. Structure of Questionnaire for Interviews with Real Estate Companies

The stock: Size of the stock, current renovation state

Energy efficiency in general and for the company: Views on profitability. Main drivers of policies. Who initiates energy efficiency measures?

Energy efficiency in conjunction with renovation: Views on coordination possibilities. Measures carried out and motives for these.

Investment assessments: Views on future energy prices, payback periods, how the risk is assessed, effect on rent levels, financing of energy efficiency measures.

Other issues: How do the energy declarations affect the company? The role of the government and need for support and probable future legislation. Attitudes towards individual metering and effect on decisions by tenants and landlords.

Appendix B. Detail on Classification of Companies

The companies have been classified using a combination of their answers to interview questions and their policy and steering documents.

Objectives/Scope of Measures

In some cases it was known in advance that extensive energy efficiency measures had been made, and these companies could be sorted into ambitious companies right away. This was the case for the Administration Led Ambitious Companies (ALACs) A and G. For other companies it was not until the interview that it became known that the company does work extensively with energy efficiency investments. This was the case for ALACs I and M, but also for all of the Policy Led Ambitious Companies (PLACs). Companies I and M were both in more of a planning phase so there is no absolute guarantee that they carry out all of the measures in the end, however, it was expressed officially on the company webpage and in documents, and they had both signed a Swedish declaration of purpose for public real estate companies, which has got more ambitious energy objectives than the official Swedish objectives. The PLACs had directives from the board, and also in the case of companies D, K and L extra financing to improve energy efficiency, and hence are expected to follow through with this. The Little Extra Companies (LECs) were sifted out from the not ambitious companies through their intention to improve energy efficiency as an end in itself, expressed through energy efficiency objectives (although not as ambitious as those above). The Strict Profit Maximizing Companies (SPMCs) all agreed that extensive measures were unlikely to be undertaken since other investments have better returns. They carry out the savings measures that have a guaranteed fast payback.

Profitability

From the interviews it was clear that the ALACs and the PLACs saw profitability in the very long run, and viewed energy efficiency measures as insurance more than as a safe investment. Companies D, K and L even had an expressed permission from the board to overlook profitability in order to fulfill energy efficiency objectives as well as employment objectives. The SPMCs on the other hand only carry through energy efficiency investments that have better expected returns than a competing project, which according to them was rare. As earlier mentioned, they do however carry out the savings measures, which will pay back almost immediately. The LECs make a more optimistic assessment of the parameters affecting profitability than do the SPMCs, but differed from the more ambitious companies in not being able to justify profitability only in the very long run, the LECs did need at least a medium run payback.

Initiator/Driving Force

One hypothesis before the interviews was that the extensive measures won´t be initiated "by themselves" but rather need a real driving force. For the ALACs the administration worked rather independently and planted the ideas of energy efficiency in the board, whereas the PLACs (however supportive of the ideas) to a larger extent merely followed orders.

Sustainable renovation strategy in the Swedish Million Homes Programme: A case study

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Abstract

The first part of the study concerns the concept ”sustainable renovation”. Four parts are identified and then used in the case study: environmental sustainability (including energy efficiency and choice of materials); social sustainability (interpreted as that the current tenants should be able to stay in the area), economic sustainability (the the project does not have to be subsidized and that there is no increase in cost for the social authorities) and finally a new interpretation that is called technical sustainability, which means that solutions with long term reliability is chosen even if this is not necessarily best from an economic and environmental perspective.

The second part of the study applies this framework to analyze the renovation strategy of a municipal housing company in the suburbs of Stockholm. This case was chosen because they had clear social ambitions and offered the tenants three alternative renovation options called mini, midi and maxi. Most tenants chose the mini-alternative and this meant that they could afford to stay and that there was not any increase in the cost for the social authorities. An investment analysis showed that the mini-alternative had a positive net present value, but that the midi/maxi alternative where more profitable. The company had no specific environmental focus and energy use was only reduced with 8%. Technological sustainability was more important for the company.

As a conclusion the study shows that a sustainable renovation is possible but that there are a number of conflicts between the different dimensions of sustainability. Giving more weight to environmental sustainability would increase cost and rents which create problems from a social perspective. From an economic perspective the midi/maxi alternatives were more profitable but then some households would have to move out because too high rents.

Keywords: housing renovation, sustainable renovation, Million Homes Programme, Sweden

1. Introduction

1.1 Background

During the period 1963-1973 one million new homes were built in Sweden. The aim was to replace housing without modern amenities and to get rid of the housing shortage that had grown when the pace of urbanization increased (Hall & Widén, 2005). The Million Homes Program is described a little more in detail in Högberg, Lind & Grange (2009). The municipal housing companies played a large role during the Million Homes Program even though the program also included private rental housing, tenant-owned cooperative housing and privately owned single—family homes. In this paper the focus is however on the strategy of one municipal housing company located in the periphery of the Stockholm Metropolitan area. In order to avoid conflicts with EU-legislation about state subsidies and competition a new law in Sweden (Law 2010:879) came into effect January 1st 2011. The law states that the Municipal Housing Companies shall act in a business-like way. Knowledge about how Municipal Housing Companies interpret the new law and how they form their business strategies related to renovation is lacking (see Elsinga & Lind 2013) and one aim of this article is also to discuss the interpretation of the law in the context of renovation projects with a social focus.

The technical quality of the houses built during the Million Homes Program is very diverse. Some buildings have already been demolished and some have been renovated (see Högberg, 2011), but it is in recent years that the issue of renovation of especially the multi-family housing stock has come to the center of the political debate (see SABO 2009). The basic technical quality of the houses is of often good (Stenberg 2013) and the question is typically not whether the houses should be demolished or not, but rather how they should be renovated and to what extent. The exception to this is only in areas with falling population and excess supply of housing, but this currently only concerns a small share of the municipalities (see BKN 2011).

The concept of sustainability has been in the center of the public debate since the Brundtland report was published in 1987. Later sustainability has been divided into three dimensions – environmental, social and economic. Several authors have discussed general tools and models that can be used to evaluate renovation policies from a sustainability perspective (Thuvander et al 2012, Gohardani & Björk 2012, Mickaityte et al 2008) and these will be returned to below. The concept of "renoviction" where cost increases due to extensive renovation will disable poorer households to move back to the renovated apartment (Westin 2011), points to possible conflicts between the need to improve the housing stock and the need to improve the housing situation of low-income households.

We consider the Municipal Housing Companies and their renovation strategies to be an important issue to study from the duality of the new legislation about acting in a business like way and the demands from a sustainability perspectives: environmental, social and economic. As the Million Homes Programme is such a large part of the housing stock in Sweden the renovation strategies will have a large influence on the Swedish housing market for many years to come.

1.2 Purpose

The main purpose of the study is to analyze and extract what lessons can be learned about sustainable renovation from a company that tries to live up to all aspects of the sustainability concept. The hypothesis is that studying in depth one company representing “the best practice” could help to clarify problems and possibilities. The aim is also to critically evaluate measures and strategies of the studied company and discuss possible alternatives.

The study is part of a broader study were also renovation strategies in the private rental stock and in the cooperative housing sector are analyzed and evaluated.

1.3 Structure of the paper

In section 2 there is an attempt to make the different dimensions of sustainability concept more operational in the context of renovation of multi-family rental housing estates. Section 3 explains and motives the method used and in section 4 the results from the case study is presented. In section 5 the results are analyzed. Conclusions and recommendations can be found in section 6.

2. The concept of sustainability in a renovation context

2.1 Environmental sustainability

The environmental classification systems like LEED and BREEAM can here be the starting point, but as the location and general structure of the buildings are given in the context of renovation, the most relevant dimensions are:

- *Energy use*: The renovation of the Million Homes Programme has been seen as a “window of opportunity” for radical reductions in the energy use in the buildings (see Högberg, Lind & Grange 2009). The share of energy from renewable energy might also be increased as result of the renovation.

- *Choice of materials*. In Sweden there are several systems for classifying construction materials and components from an environmental perspective (e.g. Sunda hus, BASTA, Svanen/EU Ecolabel) where one aspects is the absence of chemicals/hazardous materials.

- *Waste management, water management*: When renovations are made there might also be opportunities to improve features of the building that are relevant for other environmental dimensions and here we think of e.g. waste management and bicycle rooms and improvement of green areas, e.g. in order to improve water management.

-Environmental classification systems also include *the indoor environment*. Environmental consideration must take into account the residents’ health and well-being. How the tenants experience their dwelling, e.g. lighting, noise, temperature, ventilation, etc., is an aspect that is important to look at. One aspect of this is also moisture control. The Swedish system “Miljöbyggnad”, for example, has one category related to promoting buildings without damage by moisture and developing moisture secure constructions.

-*Innovation*. The classification systems encourage trying new environmentally friendly solutions, and this will also be included in this study.

-*Management*. Some of the classification systems also assess how the buildings are managed, i.e. how they are run after some time in operation. Investigating the systems used to make sure that the buildings are operated in a correct way is therefore also important. Even if this issue is most problematic in cooperative housing (see Kenne 2013), it will be studied in this case also.

2.2 Social sustainability

The concept of social sustainability also has a number of dimensions and there are at least two that are relevant in the renovation context (see e.g. Botta 2005, Weingaertner & Moberg 2011 for a general discussion about social sustainability):

- *The preservation of social capital and the local community*. More specifically a renovation contributes to social sustainability if it is carried out in such a way that households are not forced to move to other areas. There have been several critical reports in Sweden (e.g. Westin 2011) that argue that renovations have been more or less consciously designed in such a way that low income and/or socially weaker households have been forced to move out and have been replaced with economically stronger households. The renovation then tends to contribute to segregation and most probably a loss of social trust among the households that were forced to move out. Social trust is based on certain norms and values: economic equality among others (Rothstein 2011). If municipal housing companies use "renoviction" as a business strategy, it is a risk that the social trust in society will decrease. As an effect, criminality could rise since social capital in forms of prosocial norms in buildings is found to have a lowering effect on crime (see Saegert and Winkel 1998). The strategy might be profitable for the landlords in the short run but can be counterproductive for the society in the long run (Valenti and Giovanni 2013).

Renovation might be designed in such a way that it increases social capital by reducing crime and poverty among the present population, e.g. by educating and employing the residents of the area in the renovation projects, and by increasing the availability of service and job opportunities – creating a safer and more prosperous environment for those who live there now (Nilsson and Lundmark 2012).

- Another aspect of social sustainability is that the ambition should be to *create mixed communities* with a low level of segregation between different income and ethnic groups. In an area where gentrification is going on it might be motivated from the perspective of social sustainability to try to slow this process down and make it possible for poorer groups to stay in the area (longer). In areas that currently is dominated by low-income households it might instead be motivated with measures that make the area more attractive to other social groups in order to reduce segregation.

This second dimension of sustainability is however problematic for two reasons. Firstly, the strategy to create mixed communities as a solution to problems which we here might embody in the concept of 'social exclusion' is popular among policy makers but renders weak theoretic and empirical support among scholars (Galster 2007, Andersson 2006). Secondly, the strategy come into conflict with the first dimension when the focus is on areas like the one studied in this article – less attractive suburban areas rather far from the city-center in metropolitan regions. Here there is no gentrification going on and the areas are dominated by low-income households. If parts of the apartments were renovated to high standard this might lead to households with a better economic situation moving in and thereby contribute to creating a more mixed community. “Forcing” some poorer households to move out would then reduce economic segregation. Changes in the social structure might also be accomplished by adding row-top apartments or new houses with higher qualities (Boverket 2010).

In this article the choice has been to focus primarily on the first dimension of social sustainability. A renovation project then contributes to social sustainability if it is carried out in such a way that no household is forced to move because they cannot afford to pay the higher rent after renovation. We think this dimension is the most important one in the current Swedish context where there are few alternatives for poorer households that are forced to move out of a suburban Million Homes area (see Lind 2014 for a more general discussion of the tenants´ situation from a human rights perspective).

2.3 Economic sustainability

From the perspective of a housing company a renovation project can be called economically sustainable if it gives an acceptable rate of return on invested capital. The current legislation concerning municipal housing companies in Sweden actually says that the company must act in a “business like way” and this can be interpreted as that the company is only allowed to make an investment if it gives such a return (see Lind & Elsinga 2013; Bröchner et al 2013). Some minor “unprofitable” investments can be motivated from the perspective of Corporate Social Responsibility that also private companies carries out, but this can hardly be relevant for the kind of large scale renovation measures studied in this paper. Another way to put this is that if a renovation project is economically sustainable it should not be necessary to finance it by internal or external subsidies.

Another aspect of economic sustainability concerns the effect of the renovation project on social costs paid by the public sector. The economic support system for low income household in Sweden includes payments that are related to the households housing costs. If the rent level goes up when an area is renovated, part of this increase may in reality be paid by economic support from the central government or from the municipality. This kind of process when renovations lead to higher social expenditure for the municipality, and more and more households become dependent on the welfare system can hardly be seen as a situation that is economically sustainable in the long term.

2.4 Technical sustainability - a fourth aspect

The three dimensions of sustainability discussed above are mostly seen as “the” concepts of sustainability. The discussions with especially the technical staff of the company raised the questions whether there might be a fourth interesting interpretation of sustainability in the context of renovation.

In a specific situation there might be a number of technical alternatives for solving a certain problem. Some of these techniques might be older and better tested and some will be newer and more risky. Some alternatives may solve the problem for a long time and some may only solve it for a shorter time span. Choosing a more long term and well tested solution can be described as choosing a more “technically sustainable” solution. This idea also seemed to be related to taking measure before there was a real risk of breakdown and acting in a pro-active way, i.e. working with preventive maintenance.

This concept of technical sustainability cannot be reduced to neither environmental nor economic sustainability. The more long term solution might use more material and thereby, at least in some cases, affect the environment more than if a series of short term solutions are chosen. If the investor demands a rather high rate of return it might be better from an economic perspective to use the short term solutions, and also rational to wait a little longer before taking any measures. The more uncertain the long term situation is, the more rational could waiting and/or choosing the short term solution be, both from an economic perspective and also from an environmental perspective.

3. Method

The choices made concerning research method were taken in three steps.

The first step was the decision to carry out a case-study. The general advantages and disadvantages of case studies are well known, and the motive for making a case-study was that a deeper understanding was needed about how a municipal housing company could argue concerning the choice of a specific renovation strategy, especially the interaction between environmental, social and economic sustainability. Studying one case in detail would generate knowledge that are useful when in a later stage of the project more general studies of various aspects of the renovation process are planned to be made. The study is from this perspective an explorative study and a starting point for further studies.

The second step was the choice of company. As described in e.g. Högberg et al (2009) it is well known that companies follow different strategies when renovating their Million Homes Programme buildings. In the Swedish debate the company studied here has been very active and presenting their way of carrying out the renovation as a more socially sustainable way. The company presents an image as being a ”customer-oriented company” which among other things includes an ambition to renovate in such a way that no household is forced to move because of economic reasons. By studying closer how they actually worked with this and to what extent they live up to their ambitions important knowledge could be generated about how a sustainable renovation could be carried out - and also how the strategy is related to goals about environmental and economic sustainability.

In the third step an interview study was designed and persons with the positions described in table 1 have been interviewed on one or several times in order to get a clear and consistent picture of what has been done, the reasons behind this and the actors´ evaluation of the consequences.

The interviews were open ended with a checklist of questions as a starting point. The most common situation was that two researchers carried out the interviews together which reduced the risk of misinterpretation and made it easier to ask follow-up questions and document the answers. Contacts were taken afterwards with several of the interviewed persons in order to clarify certain points.

Table 1 Interviewed persons

In the company
CEO
Members of the board of the company (political representatives elected by the municipality).
Head of Property Management
Head of Property Marketing Director and head of Customer Service Staff member responsible for Leasing and Tenancy Agreements Staff member responsible for Social Lease Contracts
Outside the company
Representative of the Tenant´s Union in the area
Public official responsible for the Social Lease Contracts of the Municipality

4. Empirical results

4.1 General background to the current design of the renovation programme

In order to understand the current renovation policy of the company it is important to understand earlier projects and decisions related to that.

In the first area that the company renovated (area A) the idea was to renovate whole buildings to a standard that was on roughly the same level as newly constructed houses. For a typical 3- room apartment the renovation cost this meant a cost of almost 1 million SEK per apartment. The project turned out to be much more costly than expected and there were protests from the tenants. Given the suburban location of the areas and the relatively low attractiveness, high increases in the rent level were difficult to carry out also from a market perspective.

When a new CEO was hired this renovation policy was stopped and there were two explanations for this. The first was financial feasibility. Even if it would be possible to increase the rent in a way that made the renovation profitable, the company judged that it would not be possible to raise enough capital to carry out his type of renovation in the whole of the company´s housing stock that were built during the Million Homes Programme. Roughly 3000 of the company´s 5000 apartments were built during that period.

One complicating factor that should be mentioned is the balance sheet effects of such a renovation policy. As the property values for rental housing in suburban areas are rather low, it might be the case that the market value of the properties after the renovation are lower than the sum of the original book value and the renovation cost. The difference would then have to be booked as a cost and then the company would have to report large losses and this was not judged to be possible (see Nordlund 2012 for a discussion of these problems). The same situation with high reported losses can occur if measures that are classified as maintenance must be reported as cost in the year when they are carried out. In the Swedish regulations, maintenance is defined as measures that restore the original quality of the building, and a number of things carried out during a renovation project could be classified as maintenance. The effect of reporting this as cost would then be high reported losses for the company if they carry out costly renovations. These accounting rules are now changed and all long term measures should now be booked as investment. The first effect – that market values may not be high enough after renovation – is however still a potential problem for companies carrying out large scale renovations in areas with low market values.

The second reason for stopping the initial renovation policy was the social dimensions. The political majority and the new CEO believed that it was socially unacceptable and perhaps also economically risky to renovate in such a way that a considerable number of the current tenants could not afford the new rent. This would either lead to households moving out or to increasing costs for the social authorities. Higher tenant turnover and having many apartments with rather high rents in an area that is not among the most attractive could also be seen as risky from a strict economic perspective. Currently the housing shortage is high in the Stockholm region so it might be possible in the short run to find tenants willing to pay the high rent, but this might not be the case in a longer perspective.

Even if the goals of the renovation was changed and the focus was more on current tenants and their needs and economic situation, the renovation still demanded a large amount of capital. In order to raise capital the company therefore decided to sell part of the housing stock built during the Million Homes Programme (approximately 600 apartments). Given the social ambitions and political goals of the municipality such a sale could be expected to be controversial unless the right buyer could be found and here it turned out that the timing was very good. After the financial crisis in 2008 several of the Swedish public pensions funds started to see the real estate market as a more interesting alternative and a number of new real estate companies were started (see Larsson 2013). These new companies had different focus but the housing market was of interest for several of the companies and they were also seen as more long term and less speculative than ordinary private companies. The Social Democratic majority in the municipality saw it as more legitimate to sell to a company owned by a government pension fund than to "ordinary" private companies. One of these pension fund controlled companies also had a leading former Social Democratic politician in their top management team and this could also have contributed to make a sale more politically acceptable.

4.2 Basic description of the current renovation strategy

The company describes the renovation strategy that has been implemented in recent years as related to the following three aspects.

- Technical aspects: What do we have to do in order to keep the buildings in good technical conditions? What can and what do we want to do more than this?

- Customer aspeccts: What do the tenants want to have?

- Economic aspects: What are the economic consequences for the company of different alternatives? What are the economic consequences for the households?

It was decided that each household could choose between three alternatives for the renovation of their apartment. The information below is taken from a presentation by the CEO of the company and from the interviews.

In the *Mini*-alternative the plumbing is replaced, the bathroom is renovated, and ventilation and electricity systems are replaced. The name for this alternative can be questioned as these are rather large measures, but the focus in the Mini-alternative is on what the company sees as technically necessary for the long run use of the building.

In the *Midi*-alternative the kitchen is also renovated (except the cabinet frames).

In the *Maxi*-alternative the addition is that all interior surfaces (painting, wallpaper, floors) are renovated, so the Maxi-alternative is almost the same as a totally renovated apartment that are much like a newly built apartment.

The average costs for these renovations in the first housing estate, and the allowed rent increases, are presented in Table 2 below. The total investment below includes what the company classifies as maintenance measures (270 000 SEK per apartment). The distinction between investment and maintenance is important as the Swedish rent regulation system allows rent increases when the standard of the apartment is improved, but not for maintenance measures as they as seen as included in the standard rent.

Table 2 Economic consequences of the three renovation alternatives

Alternative	*Total cost per apartment*	*Negotiated rent increase per month*
Mini	490 000 SEK	820 SEK
Midi	510 000 SEK	1790 SEK
Maxi	685 000 SEK (11200 SEK/SQM)	1900 SEK

In the following sections the renovation will be described in more detail from the different sustainability dimensions. It should already here be underlined that the company has a clear pro-active perspective, trying to solve not only current problems with e.g. water damages but also be one step ahead and take measures before more problems arise. One aspect of this was that the company improved their information system and systematically started to check the technical systems with predetermined intervals.

4.3 Environmental sustainability

Högberg et al (2009) describes three “ideal types” when it concerns the housing companies environmental focus in the context of renovations. The three ideal types are “The Strict Profit Maximizing Company” that only carries out measures with a pay-back period of 3-5 years, “The Little Extra Company” that carries out some extra measures even if they are not strictly profitable and “The Ambitious Company” that is willing to carry out large scale investments to reach very highly set environmental goals, e.g. passive house status when it comes to energy use. The company studied here fall in the second category, but the “little extra” that it does is mainly related to customer satisfaction and not the environmental goals as such. The company has not aimed at any environmental classifications of the buildings after renovation even if it might have been possible to get a EU Green Building classification as there is considerable reduction in energy use. The same energy system is however used – district heating – and there are not investments in e.g. solar panels or in wind power.

The rents in Sweden usually include heating and this means that all reductions in heating costs or in the use of electricity in common areas directly reduces the operating costs of the company. The electrical appliances within the apartment are however paid by the tenants.

A number of measures were planned in order to reduce energy consumption. Different alternatives were analyzed, partly with the help of external consultants, before choices were made. Here are some examples:

- FTX- ventilation system. This was also motivated by increased comfort for the tenants as draft would be reduced. From a strict economic perspective it was not judged to be profitable. If a house has a natural draught ventilation system the energy losses are considered to be rather low in the first place, The energy savings by installing a FTX system will then be rather low. The houses are linked to a district heating system as is common in Swedish multi-family housing. The hydronic heating system was changed from a one-pipe system to a more reliable two-pipe system which is an advantage both for the tenants’ comfort and from a property management perspective.

- Improvements in the shell of the building. Insulations in the loft is increased to 25 cm as a thinner insulation leads to a situation where the attic floor becomes a strong thermal bridge which both means high energy consumption and problems with comfort for the tenants.

- Another measure was to put perlators in the shower fittings and thereby reduces the consumption of hot water. This was primarily done in buildings having problems with the supply of hot water and so two problems were solved at the same time.

- Low energy lightings were installed in stairwells.

- Improvements in order to increase efficiency were also possible in exhaust air heat pumps that are used in some buildings.

- In order to optimize the heating as system where it is automatically adjusted to weather forecasts (forecast control) was introduced. This alone would save the company more than 1 million SEK per year.

- Replacement of the heat exchangers in the district heating system is carried out together with the district heating company. This both increases reliability and reduces cost related to thermal losses.

FTX, forecast control, and replacement of heat exchangers are measures that have been carried out in the renovated houses leading to 8 % less energy consumed.

There have also been a number of more strategically motivated measures. Price increases for district heating in recent years have created incentives for property owners to look for other sources of heating. The company is actively investigating such alternatives and working with improving their current use of other sources, e.g.

- Upgrading the exhaust air heat pumps (see also above).

- Recovery of heat from the wastewater. Systems for this are tested in some buildings on an experimental basis.

- The company also investigates the possibility to use geo-thermal heating linked to solar panels and also use excess heat from a nearby supermarket. More than 7000 meters of drilling holes would then be used.

The company has introduced individual measurement of hot water in 1200 apartments but it has been some technical problems with this.

4.3 Social sustainability

Social sustainability was important for the company and the first aspect of this was the design of the process for carrying out the renovations. The Mini, Midi and Maxi-alternatives reflected the failures of the renovation in the first area and the alternatives and the rent increases were negotiated with and approved by the Tenants' Unions.

Staff from the company contacted each household in order to find out about the current housing situation, e.g. specific problems with draught, and the households preference concerning their future housing situation. The household could choose if they wanted staff to visit them or if they wanted to have the meeting at the company or somewhere else. It should be underlined that the company did not want people to move to apartments in the stock that should be renovated in the future. They thought that ”everyone” should get an improvement in their housing situation and were probably afraid that there was a risk that this would create an unwanted social structure in these areas. The tenants signed a document where they agreed to the renovation.

Before the major renovation one apartment in each block was renovated to each of the different standard levels and was exhibited to the tenants to give them a clearer idea about what was planned.

There were also meetings in each block where more general features of the buildings, e.g. concerning the entrances and the green areas surrounding the houses.

In order to make the renovation process as smooth as possible temporary housing was put up near the houses that was to be renovated, as households had to be evacuated during the period when the work was carried out. They could however leave furniture and things not needed during the 8 weeks that they were evacuated. This has worked very well and the Tenant´s Union has not heard any complaints from the tenants during the process.

On average 10 % of the tenants move out when the renovation was carried out, but this is around the same figure as the normal turnover in the area. Of the remaining tenants, 85 % choose the Mini-alternative, 10 % the Midi-alternative and 5 % the Maxi-alternative.

If there had been an increase in lease contracts paid by the social authorities, so called social lease contracts, we could assume that those households would have reached a point where they could no longer afford to pay the rent. The new rent after renovation would then be too costly for the some households. The social authorities have collected data on social contracts since the year 2010 and they report that they observe no increase in social lease contracts related to the company's renovation projects.

To illustrate the effect of the rent increases due to renovation alternative Mini, we made some simple calculations with data on rent allowances available at the webpage of The Swedish Social Insurance Agency, see table 3 below.

Table 3 Net effect of the rent increase at different income levels (alternative Mini) for a single parent household with two children and a typical apartment of 3 rooms and kitchen, 70 sqm.

Before tax income (SEK/year)	Before renovation: Rent 5000 (SEK/month)		After renovation: Rent 6000 (SEK/month)		Net Rent increase (SEK/month)
	Allowance	Net rent	Allowance	Net rent	
190 000	2500	2500	3000	3000	500
200 000	2400	2600	2800	3200	600
225 000	2000	3000	2400	3600	600

Source: Figures on rents and income interpreted from PPT-pictures of the company, Nov 1st 2012.

The results of the table tells us that this tenant pay 50-60 % of the rent increase due to the renovation alternative Mini. The corresponding income raise to this net rent increase would be approximately 800 SEK/month and 9 600 SEK/year taken into account the tax rate of the municipality. That sum is equivalent to quite a high income increase of 5 %.

In a long term perspective it is important to see how the rent increase affects who will be able to rent an apartment. One aspect in then the income demands that the company have on new tenants, which is that the income before tax should be at least three times the rent. With the current rent (5000 SEK/month) the income demand is 15 000 SEK/month or 180 000 SEK per year. After the renovation the rent will be 6000 SEK/month and the income demanded would be 216 000 SEK per year, which is equal to the average income of the current tenants in the company. In the long term this means that when an apartment becomes vacant the current tenant will be replaced with tenants that on average have higher income than the tenants moving out.

4.4 Economical sustainability

From a company perspective

Economic calculations always mean a comparison between two alternatives. Often the alternative is implicit and reflected in the rate of return demanded. There is an unspecified option that would give a% in return and the question is whether the current investment opportunity gives more than a%.

But when evaluating a specific renovation project it is important to clarify the alternative to renovating in the way the company has done – or more exactly – what would be the best alternative to the current renovation strategy? There are a lot of alternative options, e.g. renovating to a higher standard for all buildings as they did in the first area or demolishing and building new houses or waiting with the renovation some more years. Given the company´s goal of being a service company with a customer focus they have already discarded the first alternative and the second alternative should be worse than the first, as the costs and the rents would be even higher if new houses were built. The third alternative – wait some years – then seems to be the best alternative. Choosing this as the main alternative can also be motivated by the results in Muyingo (2010) that indicate that private owners of Million Homes Programme houses tend to wait with renovation longer than municipal housing companies.

The calculations below consist of a comparison between the policy actually followed by the company and an alternative that consist in waiting for 10 years with the renovation. A large number of assumptions have to be made and below is a list of these. Motivating the specific assumptions is difficult, but a sensitivity analysis is made to illustrate how sensitive the results are to the assumptions.

Basic assumptions:

- The calculations are made in *real terms* – unless otherwise stated it is the assumed that everything adjusts to inflation (interest rates, rents, costs) so relative prices are not affected by inflation.

- The calculations focus on the *difference* between the two alternatives: Renovating now or waiting 10 years. The basic calculations are made for one apartment with the Mini-alternative, and then the Midi and Maxi alternatives are evaluated separately through a new difference-analysis.

- The calculation covers a *10-year period*. It is assumed that the renovated and the run-down building fall in value with the same absolute amount every year. The difference in value in year 10 is then equal to the investment made in year 1 in the renovated apartment. It could be argued that this implies that the house that is renovated now will have the same value as a newly renovated house in year 10, but that there should be a difference in value between these houses in year 10. The assumption can however be reasonable if renovation costs increase in real terms over time because of relatively low productivity development in the construction sector. If renovation costs increase in real terms then the book value of the house that is renovated in year 10 will be higher than the book value for the houses the were renovated 10 years ago.

- The real discount rate is assumed to be *3 %*. Real interest rates have been falling in recent years and a long term value could be between 1-2%, and the adding risk compensation could then motivate a 3 % real discount rate. This rate is actually higher than the real rate paid by the company for loans during the last years. To simplify calculations it is assumed that both rents and all operating costs are paid at the end of the year.

- The rents are assumed to be *constant in real terms over the 10-year period*, both the rents in the renovated and the rents in the non-renovated apartments.

- Operating costs for the non-renovated case are assumed to *include cost for water damages and other repairs on the same level as in recent years.* According to figures from the company these costs were approximately 20 million SEK in 2012 and if it is assumes that all of these are in the 3000 Million Homes Programme apartments the cost per year per apartment would be around 6500 SEK. Further assuming that energy use is reduced with 20 kWh per sqm and year then for an average apartment of 70 sqm the reduction in energy cost would be 1500 SEK per apartment (energy price 1SEK/kWh.) Other operational expenses are estimated to be 1500 SEK per apartment per year. The total reduction in operating costs would then be 9500 SEK per year. It is further assumed that the difference in operating costs will be the same for mini, midi and maxi-alternative.

The results from the basic calculations for the Mini-alternative are presented in Table 4 below.

Table 4 Profitability of the Mini alternative for a typical apartment (SEK)

Renovation cost per apartment	*490 000*
Rent increase per apartment per year	10 000
Present value of rent increases	*85 000*
Reduction in operating cost by renovation, per apartment	9 500
Present value of reduction in operating costs	*81 000*
Difference in value at the end of year 10	490 000
Present value of difference in exit value	*365 000*
Total present value of project	*+ 41 000* (531 000 – 490 000)

As we can see, the Mini-alternative is profitable for the company given the assumptions made. In Table 5 below a small sensitivity analysis is made, by first increasing the interest rate to 4 % and then reducing the reduction in operating costs with 30 % as the year that the data came from might be exceptional. As we see the Mini-alternative is still profitable even in the reduction of operating cost is somewhat lower. At an interest rate of 4 % the project shows a very small loss, but given the uncertainty in the assumptions one could say that at 4% real interest rate the project approximately breaks even.

Table 5 Sensitivity analysis for the "Mini-case" for a typical apartment, SEK

	Present value of project
Interest rate 4%	- 1000
Reduction in operating costs to 7000 SEK	+ 17 000

In Table 6 and 7 below the profitability for the Midi and Maxi-alternatives are presented. The calculations for the Midi-alternative start from the Mini-alternative and look at the changes in costs and revenues of going from Mini to the Midi level of renovation. In the same way the Maxi-alternative is compared with the Midi-alternative.

Table 6 (a) Profitability of going from "Mini" to "Midi" for a typical apartment

Extra renovation cost	*20 000*
Extra rent increase per apartment per year	11 600
Present value of rent increases	*98 500*
Difference in value at the end of year 10	20 000
Present value of difference in exit value	*14900*
Increase in present value of project	*+ 93 000*

Table 7 (b) Calculations for going from "Midi" to "Maxi" for a typical apartment

Extra renovation cost	*175 000*
Extra rent increase per apartment per year	1 300
Present value of rent increases	*11 100*
Difference in value at the end of year 10	175 000
Present value of difference in exit value	*130 000*
Total present value of project	*- 34 000*

Looking at the figures for the Midi and Maxi-alternative we can see that increasing the standard beyond the Mini-alternative would be profitable for the company, especially the Midi-alternatives. If the Maxi-alternative is compared with the Mini-alternative the Maxi-alternatives is clearly more profitable and three conclusions can be drawn from this:

- The company gives priority to social sustainability as it does not choose the most profitable alternative.

- A private profit maximizing company would renovate to higher standard.

- It is therefore questionable if the municipal housing company act in line with the new legislation that says that they shall act in a "businesslike way". This will be returned to in the final section.

From a municipality perspective

The social cost of the municipality can increase when renovations leads to either more households becomes dependent on welfare payments or households that are already dependent on welfare get higher payments as their rents increased. According to the interviews with the company and the social authorities there were no observed increase in welfare dependency related to the renovation project, but it is likely that some households got higher welfare payments now that their rents increased. It was however not possible to get any data about this. As no household was forced to move out there were also no costs for the social authorities related to helping them find another apartment.

The general housing allowances in Sweden are paid by the central government and as these are related to the rent level it is likely that there were some increases in these payments related to the renovations. These allowances have been reduced during the last decade and primarily goes to the elderly and single-parents (see Enström-Öst 2010). It was not possible to get data on housing allowances for the renovation areas but a more general study on the effects of renovations on welfare payments and housing allowances have been started up.

4.5 Technical sustainability

In the first stage of the renovation programme there was an attempt to try a more innovative "industrial" approach when renovating the bathrooms by replacing the old bathrooms with a ready-made new one. This however turned out to create serious mold problems. The ambition to reduce costs came into conflict with technical sustainability.

The choice of technical alternatives was in general determined by the idea that the buildings should be able to function another fifty years. Experience from other companies indicates that many of the technical systems start to have problems after 50 years and that this is a reasonable time-frame for technical renovations. This also reflected the customer focus of the company according to which long term and reliable solutions should be chosen. As mentioned above the company has a clear strategy to be proactive and focus on pre-cautionary maintenance strategies – instead of letting the technical systems deteriorate in the way that was done earlier. In order to accomplish this the company has introduced a new property information system combined with regular inspections of the technical systems in order to e.g find leakages in an early stage.

An example of the company's strategy to be pro-active is that there currently are plans to renovate the culverts for heating and water within the area. This is important from a service perspective as the consequences might be very serious for the tenants if these culverts break down in the middle of the winter. Renovation of the culvert system would also reduce energy losses to 1/10 of the current level even if this alone is not enough to make the renovation profitable. On the other hand the cost for damages that can occur if the technical systems break down is hard to calculate and this is also an important area for future research related to the optimal timing of renovation measures.

One further reason for carrying out planned maintenance is of course that procurement will be possible to do in a much more planned way and that this should lead to lower prices and/or higher quality.

5. Concluding analysis

It should be underlined that the case presented here should be seen as an explorative study with the aim of identifying possibilities and problems. The result points to a number of crucial issues.

- *The concept of sustainability:* There seems to be a need for a fourth interpretation of sustainability in the context of housing renovation and that is called “technical sustainability”. This means that more reliable, less risky and more long term solutions are chosen, even if this cannot be motivated from an environmental or economic perspective.

- *Priority between different sustainability dimensions*. There were a number of conflicts that the company had to take a stand on. Within social sustainability there is a conflict between a focus on the current tenants and their situation and trying to create more mixed communities. The company under study gives a clear priority to the current tenants. Economic sustainability was seen as a long term precondition for the other dimensions and the company therefore did not go as far as some other companies have done in trying to reduce energy consumption.

- *The possibility of sustainable renovation.* The case presented here shows that it is possible to reach rather high levels of sustainability in all dimensions. Even if social and economic sustainability in our interpretation was in focus, a number of environmentally motivated measures were carried out and the company also tried to act more proactive in their maintenance activities with technical sustainability in focus.

There were however also a number of more problematic aspects.

- *The role of the new legislation*. It seems that the company did not choose the most profitable alternative from company perspective. It is probable that a long term private owner would have renovated to a higher standard. The company interpreted “acting in a business like way” as “not needing any direct subsidies from the owner” and “acting professionally with a customer focus”, but this is perhaps not the correct interpretation.

- *Optimal timing*. The profitability of the renovation depends in this case on rather high operating and maintenance costs before the renovation, primarily because of water damages. If the company had acted more proactively and started the renovation earlier, it would probably not have been profitable.

- *Financial aspects*: Even if the renovation was profitable it was judged to be necessary to sell part of their Million Homes Programme stock in order to finance the renovation. An important aspect when looking at the renovation of this stock as a whole is then what happens to the stock that is sold. So far the renovation in that area has not started and it is uncertain what they will do, but the economic analysis above indicate that they probably will wait for a few more years and then renovate to a higher standard where some of the households cannot afford to move back. If this predication is correct then some areas would have to be “sacrificed” from a social sustainability perspective in order to “save” others.

- *Relation between renovation and new construction of affordable housing*. Looking at the housing market from a longer term “flow” perspective, optimal renovation strategies are related to the supply of affordable housing. If older areas are renovated to a high standard this might not be problematic from a social perspective if their either is a “filtering” down in other not so old areas or new construction of affordable housing. As none of this happens currently in Sweden, then it becomes especially important with the kind of renovation policy that the company in this case study tries to carry out where the current tenants is in focus without compromising with the goal of economic sustainability.

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Article

Organization of Laundry Facility Types and Energy Use in Owner-Occupied Multi-Family Buildings in Sweden

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Abstract: The way in which we plan and produce buildings today will influence our energy consumption in the future. This paper explores how the types of laundry facilities provided in owner-occupied multi-family buildings in Sweden have changed since the 1990s and seeks to draw attention to how this may impact energy consumption for laundry. Three factors are analyzed that influence energy consumption: the number of laundry appliances, energy performance in laundry appliances and user demand for laundry. The results indicate that there has been a change in building practices, from the domination of communal laundry rooms towards in-unit laundry facilities. The findings imply that the changes in provision of laundry facilities increase the number of appliances but do not necessarily increase energy consumption during the usage phase depending on energy performance and user behavior. Thus, developers should consider laundry facility organization when designing multi-family buildings in order to optimize the use of space and resources, given user demand and building regulations. This paper is exploratory in nature and indicates a shift in building practices that up until now has been undocumented in a research context which in turn opens up for many new research questions related to resource use but also related to the economics of developers, housing firms and households.

Keywords: construction choice; new construction; energy consumption; energy efficiency; household laundry; multi-family buildings; building practice

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1. Introduction

The way in which we plan and produce buildings today will influence our energy consumption in the future. Indeed, developers have the potential to provide better—or worse—conditions in new construction for energy-efficient behavior, for example when installing appliances. Policy initiatives such as the EU directive on eco-design for energy-related products [1] will influence the energy performance of appliances, and consumer choice and behavior will ultimately play a decisive role in energy consumption. This study focuses on the intersection of technology and behavior to investigate how the organization of laundry facilities in new construction may impact energy consumption.

For decades, the standard for laundry facilities in Swedish multi-family buildings has been a communal laundry room in the same building or block, where households can book time to do their laundry, free of charge. This paper takes its starting point in a recent empirical observation for owner-occupied housing that indicates a change in new construction. Developers seem to be increasingly installing in-unit washers and driers in each unit, and sometimes providing concurrent access to communal laundry facilities [2]. Developers, it would seem, sacrifice the economies of scale derived from a centralized laundry system for consumer choice and convenience. If these observations reflect a systematic change in building practices, how may this way of organizing laundry facilities impact energy consumption?

Energy consumption for a specific area or function will depend on three factors: the number of energy consuming appliances, the energy use per occasion (time unit), and how much appliances are used [3]. To our knowledge, only a few research studies have been done on household washing behavior in general and related to different building practices in particular. Earlier studies have, however, suggested that from a life cycle or a system perspective, communal-based infrastructure such as a communal laundry room should be environmentally better than a product-based service like in-unit appliances [4]. One possibility is that a change to in-unit appliances provides residents with increased access and freedom of choice, which lowers the threshold to doing laundry and, therefore, increases energy consumption.

The aim of this paper is to shed light on some of the recent developments in the construction of multi-family housing, and to assess how it may impact total energy use in multi-family houses. To fulfill the aims, the first research question to be answered was: How have developers designed laundry facilities in new multi-family buildings for tenant-owner associations in the past, and how are these facilities designed today? Historically, communal laundry rooms have been the norm, but our field observations indicated that in-unit appliances are becoming more common and our task was to research the extent of the change.

We then explored how energy consumption used for laundry might change if building practices change. What impact might the new type of laundry facilities have on energy use in a building? A different arrangement might result in higher energy consumption for doing laundry if the number of appliances increases, if the energy performance of in-unit appliances is worse than that of communal appliances, and if tenants increase their demand for laundry.

Our approach is to document the building practices of the latest thirty years and not an attempt to explain why the changes have occurred. Furthermore, we only look at new construction for housing cooperatives in Sweden.

The organization of this paper is as follows. In Section 2, we provide a brief background of laundry facilities and household energy consumption in Sweden. We also introduce the analytical framework by describing the current situation for the three energy-driving factors. Section 3 is the methods section where we explain how the collection of data and the calculations were carried out. In Section 4, we present the empirical results from the documentation of building practices. Possible implications of the empirical findings are analyzed in Section 5. The results are discussed in Section 6 and some concluding remarks can be found in Section 7.

2. Background and Analytical Framework

2.1. The Communal Laundry Room

The communal laundry room is a typical Swedish concept, springing from the political ideal of the equal right to stay clean [5]. During the interwar years, various political and social movements were making their voices heard in an effort to reform the housing sector in Sweden and improve living standards and hygiene in the cities. Pioneering efforts were carried by the Swedish Tenant Owners' Association (HSB), a housing firm, which was the first to build communal laundry rooms in multi-family buildings already in the early 1920s. A widespread breakthrough promoted by municipal housing firms during the post-war era helped make the communal laundry room standard in Swedish multi-family buildings. In the 1940s, communal laundry rooms were routinely planned in new developments and became a norm in the 1950s. Soon, 80% of the households in multi-family buildings had access to communal laundry rooms which increased to 90% in the 1960s and in the 1970s had grown to the vast majority of households [5,6]. Today the approximately 30,000 communal laundry rooms in Swedish owner-occupied and rental multi-family buildings are equipped with an estimated 200,000 washing machines. In addition, there are an estimated 800,000 in-unit washing machines in multi-family buildings and approximately 270,000 common and in-unit tumble dryers [7–9].

2.2. Owner-Occupied Multi-Family Housing and Laundry Facilities

Housing cooperatives, a form of tenant-owner tenure, account for 38% of the Swedish multi-family housing stock or approximately 2,382,000 dwellings. In 2011, 8413 units in housing cooperatives were completed in Sweden, which was 51% of the total construction of multi-family buildings [10]. Housing cooperative buildings are formally owned by a tenant-owner association (TOA), which gives all the co-owners some influence over building-related issues. The TOA board most often acts on behalf of its members; the exact issues and their extent depend on the TOA statutes.

According to the Swedish minimum building requirements (BBR), multi-family housing needs to offer a communal laundry in or close to the building, independent of tenure form. Historically, the laundry rooms have been placed in inaccessible spaces in the building's basement, but because of accessibility regulations as well as safety and well-being, it is becoming more common to place the laundry rooms on the ground level, with windows [5]. If there is no communal laundry room, the BBR state that every unit should have a specified and defined space for laundry machines [11]. For owner-occupied housing, the communal laundry room provision is an internal matter for the TOA. There are not specific requirements for these communal spaces, but industry recommendations call for at least two washing machines and one dryer and/or drying cabinet for every 35 units, if possible [12]. This allows each household at least weekly access to a three-hour time slot (laundry hours are usually restricted due to the noise), corresponding to approximately six laundry cycles per week.

Different washers and dryers have different specifications and there may be a tradeoff between their different features, such as size, cycle length, energy efficiency, noise level, operation costs, maintenance costs, and life length. For example, communal laundry rooms are typically equipped with larger and more durable appliances ("professional" washing machines and tumble dryers) to endure frequent use. The wash cycle is usually shorter than that of in-unit appliances to allow residents to maximize the limited laundry time available. In-unit appliances are usually slower and quieter than professional appliances [5,7,8].

Traditionally, the charge for using the communal laundry rooms has been included in the TOA fee. The fee covers operation and maintenance of the facilities and the users pay for laundry detergent, *etc*. When technically feasible and allowed by the TOA, it has been possible for tenant-owners to install in-unit washing machines on their own initiative. The operation, maintenance, and replacement of in-unit appliances are the responsibility of the tenant-owner.

2.3. Determinants of Laundry-Specific Energy Consumption

The variation between households in energy use for laundry may largely depend on household composition and other socio-economic and cultural characteristics [13–16]. The average Swedish multi-family building unit consumes around 3000 kWh of electricity per year. Studies of household energy consumption indicate that 7%, 210 kWh per year, of household electricity in multi-family units is used for washing and drying laundry [13,14].

Household energy use in general, and electricity use for doing laundry in particular depends on three factors: (i) the number of appliances; (ii) the energy use per occasion/time unit (energy performance); and (iii) how the residents use the appliances. The first two factors are technical and the third is behavioral. Below is an attempt to describe the current situation.

(i) Statistics Sweden [17] reports that in 2006–2007, almost 75% of the population 16–84 years of age had access to a washing machine of their own. The corresponding number in housing cooperatives (usually multi-family) was 57%. One third of the households living in multi-family buildings (rental) stated that they had in-unit washing machines. Tumble dryers, on the other hand, were rare among households in multi-family buildings [13]. In a survey carried out by Zimmerman [14], 200 Swedish households living in multi-family buildings stated that they possessed on average 0.51 washing machines and 0.15 tumble dryers. Depending on household type (singles, couples, and families, aged 26–64 or +64 years) possession varied between 0.39–0.63 washing machines and 0.1–0.21 tumble dryers.

(ii) Technological advances have increased the energy efficiency of washers and dryers. Between 1993 and 2013, energy consumption per cycle in new washing appliances has been reduced by more than 50%. Energy efficiency in tumble dryers improved by 12% between 1995 and 2005. One driving factor has been the energy labeling of energy-consuming appliances, which requires manufacturers to display energy performances on individual appliances to guide consumers in making energy efficient choices [1,18,19]. The labeling has been successful and the variation in energy performance in most modern appliances today is so small that energy efficiency has become a "secondary property" relative to other features of the appliances.

(iii) As technology and social norms have changed, laundering has increased in the past century for behavioral reasons. An increased individualization and higher demands for efficiency have enabled the transition from past processes of washing under difficult conditions to disinfect the laundry to today's laundering, which oftentimes is done to feel "fresh", regardless of actual "dirt". This means our laundry habits have changed from washing infrequently and for long periods to washing more often but for short periods [5,13,20]. Swedish households have more than doubled their laundry loads between the 1930s and the 1980s, and US households have tripled their loads since the 1950's [18,19].

In a Swedish study from 2003, using survey data for 600 Swedish households showed that approximately 52% of the households studied used their washing machine 4–6 times a week [13]. In another study, Zimmerman [14] monitored and measured the laundry patterns of 400 Swedish households from 2005 to 2007 and estimated that Swedish households living in multi-family buildings wash on average 2.9 cycles per week. Internationally, similar washing patterns have been observed. A German consumer study showed that households washed 2–6 cycles per week and other EU and US data is within this range, with approximately 5 cycles per week [21–23].

For tumble dryers, a study of 250 households in Poland, France and the UK showed that the average use was 2.3 drying cycles per week in the summer and 3.6 cycles in the winter [24]. In the US, the Department of Energy estimates that the average number of cycles per week is 5.5. This figure might seem high, which may be because washing loads are split into two or more clothes dryer loads [25].

As mentioned previously, variation between households in demand for laundry is influenced by various factors, such as dwelling size, age, household income and tenure [13,14,17,23,26–28]. As Davis [16] has showed, demand for laundering is endogenous with respect to which appliances households buy. Households that put a relatively high value on the household service laundry will buy more efficient appliances, which is not to be confused (altogether) with more efficient appliances yielding higher user intensity. Changes in circumstances, such as a new organization of laundry facilities, may impact the marginal (alternative) cost and the marginal utility residents experience from doing laundry, the extent of each impact will ultimately determine changes in laundry demand.

3. Method and Data

3.1. Empirical Study

In the empirical part of this study, we focus on the connection of building practices and factor (i), the number of appliances. Data was collected in two steps. First, an on-site survey was undertaken to document building practices in Swedish multi-family buildings in different periods. The study objects were multi-family buildings owned by housing cooperatives in Stockholm central suburban areas. Buildings with units for sale were surveyed in November and December 2012 and in March 2013. A checklist was used. A total of 31 buildings were surveyed, 9 of which were built in 1990 to 1991, 9 were built between 2000 and 2002, and 13 buildings were built between 2009 and 2011. Data was collected for 72 features in four categories: the building, the unit, the kitchen, and the bathroom. The presence of a communal laundry room was one of the 15 features looked for in the building category. An originally installed washing machine, tumble dryer or a combined washer/dryer were three of the features looked for in the bathroom category. For more information about the data and data collection, see Borg and Song [2].

Second, to document current practices the historical data were supplemented with the latest information from the six biggest Swedish developers. This included ongoing construction projects that had been initiated no earlier than 2012. Information about laundry facilities available in multi-family buildings currently under construction was collected through the firms' web pages. Data was collected from Stockholm and the other four largest cities in Sweden (Gothenburg, Malmö, Linköping, and Uppsala) to ensure that a (possible) observed trend wouldn't be just regional, such as for Stockholm central suburban area. In total, information from 136 multi-family projects was collected. In 11 cases there were difficulties in collecting information through the web pages so email requests for information were sent to the project managers, who promptly answered.

3.2. Analysis

To analyze the possible impact the observed change might have on energy consumption, we revisit factor (ii) and (iii) in a numerical example to illustrate how the organization of laundry facilities may influence energy consumption. The numerical example compares three type buildings which reflect three ways of organizing laundry facilities. To facilitate comparison, the type buildings are all assumed to be new construction and each of the model buildings has 35 units.

Our base case, building 1, reflects the traditional way of organization and has one communal laundry room equipped with two washing machines and one tumble dryer. Type building 2 is a reflection of the new laundry organization with only in-unit washing appliances, one washing machine and one tumble dryer per unit, a total of 35 washing machines and 35 dryers for the building. Type building 3 reflects the transition period and is designed with both a communal laundry room and in-unit appliances. Type building 3 thus has 2 + 35 washing machines and 1 + 35 tumble dryers.

To get an indication of energy performance in our example, we used the European Union consumer information website Topten [29], which reflected the best available technology choice available on the market. Assuming the best available technology is chosen, the difference in energy performance between communal laundry appliances and in-unit appliances will depend on the different standard in each category. Topten mainly ranks household appliances and had no category for (semi)professional washing machines. Information about (semi)professional appliances was taken from the Swedish Energy Agency and their testing lab [7]. To facilitate comparison per washing cycle, we chose examples of similar size even though communal appliances on average probably will have a higher capacity.

Using the three type buildings and the chosen characteristics, we calculated the average energy consumption for laundry over the course of a year. The results for the in-unit case and the in-unit plus communal laundry room case, respectively, were compared to the traditional communal laundry room case.

Note that we only consider the usage phase and not the energy use before and after the active life cycle of the appliances. Considering a life cycle perspective, the energy savings from replacing old appliances with more efficient ones should be contrasted to the energy needed to manufacture the new appliances. However, the energy consumed by an appliance during the usage stage is 80% of its life cycle energy use, thus far greater than that used in other stages [4,30]. It is also important to consider other energy needs, for example to light up and heat the facilities. This, however, is beyond the scope of this paper.

4. Empirical Results

Changes in Construction Practices

Over the course of the studied period, there have been clear changes in construction practices (Table 1). Our on-site observations revealed that buildings constructed from 1988 to 1991 follow the practice of having a communal laundry room. The buildings had not installed in-unit washing machines or tumble dryers as standard items (Table 1, upper panel).

Table 1. Laundry facility organization from late 1980s to 2010s and 2012 onwards.

Laundry Facility Organization from Late 1980s to 2010s					
	Construction Year	**N**	**Only Common (n)**	**Only in-unit (n)**	**Common + in-unit (n)**
On-site observations, Stockholm	1988–1991	9	100% (9)	0%	0%
	2000–2002	9	0%	11% (1)	89% (8)
	2009–2011	13	0%	23% (3)	77% (10)
Laundry Facility Organization in New Construction Projects, 2012 onwards					
	Local Market	**N**	**Only Common (n)**	**Only in-unit (n)**	**Common + in-unit (n)**
Developer observations	Stockholm	76	0%	78% (59)	22% (17)
	Gothenburg	25	0%	84% (21)	16% (4)
	Malmö	15	0%	80% (12)	20% (3)
	Linköping	4	0%	100% (4)	0%
	Uppsala	16	0%	75% (12)	25% (4)
	Total	136	0%	79% (108)	21% (28)

After 1991, a major shift in laundry facilities can be observed among multi-family buildings owned by housing cooperatives. Developers rapidly shifted from designing buildings with communal laundry rooms towards installing in-unit facilities. The survey of buildings that were constructed around 2000, showed that all the units were designed with in-unit washing appliances. However, supplementary communal laundry rooms were available in most of the buildings. The overall design of multi-family buildings remained unmodified during the first decade of the 21th century. Until around 2010, buildings were designed with in-unit appliances, sometimes in combination with communal laundry rooms (Table 1, upper panel).

The information on projects under construction during 2012 and onwards reveals that the design of new buildings has shifted rapidly (Table 1, lower panel), with a clear pattern towards the use of in-unit appliances. A second trend, almost as striking, is the move away from communal laundry rooms. On-site field studies have not been done for the other cities. However, there were no indications from the websites or emails from project managers that this was a regional trend concentrated to Stockholm (Table 2, lower panel).

Table 2. Model buildings and key characteristics.

Technical data	**Building 1**	**Building 2**	**Building 3**
Washing appliances	2 communal washing machines [a]	35 in-unit washing machines [b]	2 communal washing machines [a], 35 in-unit washing machines [b]
Energy use per washing cycle, kWh (at half load 40/60 degrees)	0.41/0.65	0.55/0.60	
Drying appliances	1 communal dryer [c]	35 in-unit dryers [d]	1 communal dryer [c], 35 in-unit dryers [d]
Energy use per drying cycle, kWh	1.61	1.08	
Laundering availability	Five daily laundry slots 7 am–10 pm (on average one three-hour slot per household per week)	Unlimited 24 h	Unlimited 24 h
Behavioral data	**Building 1**	**Building 2**	**Building 3**
Charge	Included in monthly fee	Electricity	Electricity
Washing cycles per day per building	25	25	45
Drying cycles per day per building	15	15	15

[a] Electrolux W465H, 6.5 kg washing load [7]; [b] Adorina SL V-Zug, 7 kg [29]; [c] Bauknecht TRW5070, 7 kg washing load [29]; [d] Siemens WT48Y7W1 8 kg washing load [29].

5. Implications of Changes in Construction Practices

5.1. Factor (i) Change in Number of Appliances due to Changes in Building Practices

Clearly, the two newer ways of organizing laundry facilities in buildings 2 and 3 have an impact on factor (i) and increase the total number of appliances. If all of the in-unit appliances would be utilized to their maximum, the total number of hours of washing would be much higher in buildings 2 and 3 than in building 1. Moreover, in a communal laundry room there is also the possibility to restrict households' access to the facilities to certain hours.

5.2. Factor (ii) Differences in Energy Performance due to Changes in Building Practices

For a given laundry session, energy performance may vary between the appliances that are used communally and privately. Studies have shown that communal appliances are often more modern because of a higher replacement rate [4,13]. Different industry standards and user demands may require different energy performance. In-unit appliances as well as "semi-professional" appliances for communal use are often smaller and better adapted to the smaller household size of today. This means that each cycle consumes less energy than that of professional appliances, but also that they are less energy efficient per kilogram of laundry (assuming similar energy standards and washing at full load).

On the other hand, there may be differences in what appliances are installed depending on who is responsible for operation and maintenance. Appliances in rental housing have, for example, been found less efficient than appliances in owner-occupied housing [31,32]. A similar principal-agent problem arises in our example if developers choose less efficient in-unit appliances that are cheaper upfront because the TOA or the tenant-owners pay for operations.

We have no information about the appliance choice developers make, but we do know that energy performance of new appliances in general is high today. We also know that the difference in energy performance between appliances might be the result of the concurrent demands that appliances need to fulfill, such as noise levels or washing cycle length. This implies that the major difference is expected to be between communal and in-unit appliances, rather than within the various communal or the various in-unit appliances.

Table 2 shows the energy performance of in-unit and communal appliances of similar capacity based on the best available technology. The communal washing machines use less energy than the in-unit appliances per 40 degree wash, but the reverse is the case per 60 degree wash. Communal tumble dryers use almost 50% more energy than in-unit tumble dryers. Total energy consumption will thus depend on how the appliances are used.

In our numerical example, we assume that every household in building 1 uses its weekly time slot and washes five cycles a week, which yields 25 wash cycles per day for the building. We assume they use tumble dryers three times per week, resulting in 15 drying cycles per day for the building. These laundry patterns are within the range of previous studies [13,14,21,23,24].

For building 2, we hold demand for laundry constant and assume that households with in-unit appliances launder with the same frequency. For building 3, we assumed the same common laundry pattern as for building 1 and added half of the laundering from building 2. This corresponds to a situation where households continue to do laundry in the communal facilities and throw in the occasional batch of laundry to have it freshened up as indicated in Karlsson and Widén [3].

Table 3 shows the resulting annual energy consumption for the three type buildings. Looking at washing separately, in-unit appliances are more energy consuming which results in higher energy consumption in building 2 than in building 1. For drying, the pattern is the opposite; energy consumption for drying is higher in building 1 than in building 2. Taken together, with the same demand for laundry, the total effect is that building 1 with communal laundry room uses more energy than building 2 with in-unit appliances. The double access in building 3 of course yields much higher energy consumption than building 1, since we simply added washing in this scenario.

The difference between building 1 and 2 in energy consumption results from the technological differences in appliances and is an indirect result of the changed building practices. The difference between building 1 and 3 results from technological differences and is reinforced by a difference in behavior, an increased demand for laundry.

Table 3. Annual energy consumption, kWh (difference compared to base case "Building 1").

Appliance Type	Building 1: Communal (Base Case)	Building 2: In-unit	Building 3: Communal + In-unit
Washing	4835	5245 (+8.5%)	7460 (+54%)
Drying	8815	5885 (−33%)	8815 (+/−0%)
Total	13,650	11,130 (−18.5%)	16,275 (+19%)

(1) The calculations were made by multiplying the assumed number of daily washing and drying cycles with the energy consumption per washing/drying cycle (using the 40 degree figure for half of the wash cycles and the 60 degree figure for the other half) and then multiplying by 365 to get the annual figure; (2) Dividing the total energy consumption by average dwelling size in new construction (99.1 m^2, in 2009) [33] yields an Energy Use Intensity (EUI) of 138 kWh/m^2/year, 112 kWh/m^2/year and 164 kWh/m^2/year respectively.

5.3. Factor (iii) Differences in Demand for Laundry due to Changes in Building Practices

Thus far we have seen that a change in building practices from communal laundry room to in-unit appliances leads to a higher number of appliances. One consequence of this is that communal appliances are replaced by in-unit appliances. The appliances used in either type of facility will have different energy standards, given best available technology, which then implies a change in total energy consumption for laundry. Based on the differences in energy consumption in Table 3 above, we altered the in-data for laundry behavior and looked for the tipping points that would be necessary to make the two cases (only communal laundry room *versus* only in-unit appliances) to break even in energy consumption. In addition to identifying the tipping points, we contrasted with a change in demand in the opposite direction.

The direction of a change in demand for laundry resulting from a change in building practices is not obvious. If the tenant-owner is directly responsible for all laundry-related costs, according to economic theory, he or she should launder less than when costs are shared communally. On the other hand, to higher income households (who are likely to live in cooperative housing units), the value of time is higher and the direct energy cost of laundering might be marginal. Households with in-unit appliances are closer to the appliances and basically have no time restrictions on their laundering. This makes it more convenient to do laundry, in which case they might do it more often to "feel fresh". On the other hand, some households might prefer to use the communal laundry room and do all their laundry at once.

We now compare only building 1 and 2, and look at the possible impact of changes in laundry demand from different organization. Table 4 shows the change in energy consumption resulting from a change in demand for laundry. Scenarios a-b illustrates an increase in demand with in-unit appliances and scenarios c-d illustrates a decrease in demand with in-unit appliances.

The 35 households with in-unit appliances would have to increase the total washing in the building from 25 to 37 times per day, or do on average 7.4 (instead of 5) wash cycles per week per household (keeping tumble drying frequency constant) to consume as much energy for laundry as building 1 does (Table 4, scenario a). If we, instead, keep washing constant and change only tumble drying in the in-unit appliance case, the 35 households would have to run a total of 22 drying cycles per day (4.4 drying cycles per week per household) to consume as much energy as building 1 does (Table 4, scenario b).

Table 4. Tipping points in energy consumption due to changes in laundry demand.

Alternative scenario for building 2: Assumed changes in laundering behavior	Energy consumption, kWh/year Building 1: Only communal	Energy consumption, kWh/year Building 2: In-unit
Base case consumption	13,650 (4835 + 8815)	11,130 (5245 + 5885)
Increase in-unit washing to 37, all else equal.		13,650 (7765 + 5885)
Increase in-unit drying to 22, all else equal.		13,875 (5245 + 8630)
Decrease in-unit washing to 20, all else equal.		10,085 (4200 + 5885)
Decrease in-unit drying to 10, all else equal.		9170 (5245 + 3925)

If in-unit appliances lead to households reducing their demand for laundry, the energy consumption of building 2 would naturally be further reduced. In the first example, drying was kept constant at 15 cycles and washing was reduced to 20 cycles per day, corresponding to 4 cycles per week per household (scenario c). In scenario d, washing was kept constant while use of in-unit tumble dryers in building 2 was assumed to drop to a total of 10 cycles per day, or 2 cycles per week per household. In both of these cases, laundering in building 2 required less energy than laundering in building 1 did.

6. Discussion

6.1. Changes in Building Practices and the Number of Appliances

When developers install in-unit appliances, whether to replace or supplement the communal laundry room, the total number of appliances for a given multi-family building will increase. Differences in wear and tear may cause the appliances to wear out at different rates and hence to need replacing at different intervals. To the extent that less frequent use of in-unit appliances give them a longer life cycle, the total number of common appliances might increase compared to the number of in-unit appliances over an extended time period. A shorter replacement interval, however, should not be enough to outweigh the initially higher number of in-unit appliances over a specific period of time and we expect an increase in the total number of appliances.

The shift in construction practices towards including more in-unit appliances have occurred without any formal requirement such as a new regulation. One explanation might be that there is a customer-driven demand for individual laundry facilities in the units. Studies have shown that the communal laundry room is a common place for conflict and that residents would prefer to avoid this [5,34]. In addition, other regulations have changed with implications for design and planning; building regulations now require better accessibility which has led to bigger bathrooms [35]. The enhanced bathroom size in combination with increased customer demand for in-unit appliances allows developers to make use of otherwise unused space. At just a small additional cost, they can meet the customers' demands and enhance customer utility but also, it is assumed, demand a price premium on the (new market) selling price.

Developers are also increasingly abandoning the communal laundry room. A plausible reason is the alternative cost—by doing so they are able to utilize the then available space to increase the size of the units or even build an additional unit, which may generate higher revenue. To the extent that they still build communal laundry rooms, this is more often than before placed on the ground floor. This implies that there will be a tradeoff between lower costs for underground construction and an alternative use for ground floor space. For this reason, we expect the communal laundry rooms to gradually disappear. Another possible explanation might be that energy consumption in buildings is high on the agenda these days. Mandatory energy performance certificates and other building performance labelling schemes for sustainability aspects signal the importance of low energy consumption. Electricity use for the communal laundry room is included in the building energy use and energy use for in-unit appliances is included in household energy use, in the official statistics as well as well as in how energy is charged. Organizationally moving laundry specific energy consumption to the households thus will make energy performance of the building look better even if total energy use would be the same [36]. Again, our examples show that energy consumption doesn't necessarily increase, but if we want to reduce total energy consumption we need to holistically consider what impact this kind of changes will have.

6.2. Changes in Building Practices and Energy Performance

As we have seen, there are differences in energy performance between modern communal and modern in-unit appliances. As long as this difference remains, even if developers aim for the best performance in appliances there will be a difference in total laundry-specific energy consumption between the two cases, provided demand for laundry stays unchanged. In our example, this was to the advantage of in-unit appliances when summarized, but differed between washers and dryers.

A change in building practices may also result in an agency problem. If the communal laundry rooms disappear, there is a risk that developers will install cheaper and less energy-efficient in-unit appliances to maximize profits. Tenant-owners will be left with the operation and maintenance bill over the working life of the energy consuming appliances. However, observations from our new construction projects indicate that there is remedy to this problem; developers often offer tenant-owners a choice between appliances with different energy performance. This ensures that the person who will be responsible for future operations and maintenance also has the option of paying more upfront to minimize life cycle energy consumption and costs.

6.3. Changes in Building Practices and Household Demand for Laundry

Our calculations show that installation of in-unit appliances could actually lead to a reduction of laundry-specific energy consumption in multi-family housing. However, a reduction in *building* energy consumption may be outweighed by an increase in *household* energy consumption if households with in-unit laundry facilities also increase laundering frequency. As shown in the tipping point analysis, only 2.4 more wash cycles per week and household were needed for in-unit laundering to exceed the energy consumption of communal laundering. Perhaps this possible rebound effect is easily achieved when laundry facilities are more readily available. On the other hand, a shift to in-unit appliances also implies a relocation of laundry specific operation and maintenance costs from the TOA collective to the household, which would send more correct (price) signals and create incentives for energy saving behavior. Which of these incentive effects remains stronger is an empirical question. According to Davis [16], there is only a small rebound effect of having more efficient appliances (and thus a lower marginal cost), mainly because households that put a high value on laundering weigh this into the appliance purchasing decision. In our case, when households have less influence over appliance choice in the communal laundry room case this aspect might be more relevant.

When thinking about how a change in laundry facilities organization impacts laundering behavior, we need to consider two factors: utility and cost. If households find it inconvenient to do laundry in a communal laundry room, for example because of conflicts, distance, or time restrictions, their utility will increase with the increased freedom and convenience of having in-unit appliances. On the other hand, leaving households with no other choice than to launder in their own unit could imply a different type of inconvenience. For example, if households dislike having their washing machine running frequently (instead of being able to use parallel washing machines, possibly with bigger capacity), or if they dislike being responsible for operation and maintenance, this may lower the utility of households with (only) in-unit appliances.

Changes in the marginal (alternative) costs may occur for partly the same reasons. Proximity and easy access to laundry facilities may lead to a higher frequency of washing among residents if the time cost is lowered. The changed social norms about "feeling fresh" and the larger variety in washable fabrics that need separate treatment are examples of factors that would lead us to assume an increase in laundering, if they before were constrained by restricted access to the communal laundry facilities. An indication of this tendency was reported in Karlsson and Widén [3]. Furthermore, residents may overuse or be careless with communal appliances if they know they only have to pay for a fraction of the operation and replacement cost, compared to having to pay for an in-unit replacement themselves. Conversely, the higher costs for residents when being directly responsible for the operation and maintenance of their in-unit appliances may contribute to a reduction in washing.

Ultimately, we have to compare the households' marginal utility of one extra washing or drying cycle to the marginal cost of that extra cycle after a change in laundry facility organization to be able to evaluate total impact. Tumble drying serves as an example of how this could play out. Previous studies have shown that households that have in-unit tumble dryers use them less frequently because of the high amount of energy they consume [3]. The difference in energy consumption between communal tumble dryers and in-unit tumble dryers is relatively large. If we assume that households run their tumble dryers the same number of cycles, the technological difference results in lower energy consumption for the in-unit case. Thus, the high energy consumption and increase in directly related households cost may lead to a decrease in demand despite the fact that tumble drying should give households with in-unit appliances a higher utility, e.g., thanks to avoiding having to clutter the home with drying laundry,. If the above is a realistic description of reality, price signals are expected to reinforce the energy-saving impact of the technological difference for households with in-unit appliances instead of communal laundry rooms.

7. Conclusions and Future Research

In this paper, we have studied how developers' building practices have changed in the case of laundry facility provision. Our study shows that there has been a shift in practices; in new construction for tenant-owner associations, the communal laundry rooms have largely been replaced by in-unit appliances. Judging from current new construction projects, this trend will continue and the communal laundry room will become history. We can only speculate about the motivation behind this shift, but, given our observations, we can consider the various impacts the change might have on energy consumption.

Our numerical example shows that laundry-specific energy consumption does not necessarily increase during the usage phase from the shift to having only in-unit appliances. The somewhat unexpected reduction in energy consumption is driven by technological factors; assuming identical behavior and given the lower energy consumption of in-unit appliances, the total energy consumption will be lower. This result is only valid as long as the differences in energy performance between communal and in-unit appliances remain.

Lower energy consumption resulting from a shift to in-unit appliances may be reinforced by changes in behavior depending on how households value the utility of experiencing the full benefits of easy access to the appliances as well as the full operation and maintenance costs for them. If households adopt an energy-saving behavior by filling up loads (or using "half-load" settings) and avoiding peak hours (when the electricity often comes from less clean energy sources), a lower energy consumption could also reduce climate impact. On the other hand, if awareness or price signals aren't strong enough, a shift to in-unit appliances may result in an increased demand for laundry and higher energy consumption. Policy makers, developers and/or property owners can try to encourage energy saving behavior by informing households about laundry related energy-saving measures.

One limitation of our study is that we have made simplifications to enable comparison. For example, we never considered a drying cabinet. This piece of high energy-consuming equipment is common in Swedish communal laundry rooms but rare as an in-unit piece of equipment. If available, a drying cabinet could make the communal laundry room energy consumption even higher, why we argue that our calculations capture the main tendencies related to technology and behavior. On the other hand, communal laundry facilities might offer better opportunities to hang-dry laundry, which could have the opposite effect.

Our study has awoken several questions for future research. One issue is whether the observed shift in construction choice also will include rental multi-family buildings. Most multi-family buildings constructed by or for rental housing firms are still designed with only a communal laundry room, but anecdotal evidence suggests that there is a tendency to provide also rental units with laundry appliances. How common are in-unit appliances in rental housing, and do they replace or supplement communal laundry rooms? Furthermore, energy consumption during the usage phase is not the only aspect influenced by changes in construction practices. Our analysis could also be extended to include the life cycle of resources in the production of the appliances and other inputs (e.g., water and detergent) used, from the assembly stage to disposition.

As far as energy performance and laundry behavior are concerned, it would be interesting to study the possible agency problem related to life cycle cost and what appliances are chosen. It would also be very interesting to see if the change in building practices does in fact influence demand for laundry. Will the impact of the assumed increased convenience or the additional cost be higher? As Davis [16] points out, the impact on demand for laundry of a change in facilities would ideally be studied by randomly assigning the facilities to households and control for household and other characteristics, or at least, as in the study by Davis, control for endogeneity by considering previous washing habits. Unfortunately, as far as we are aware there is no data available to support either of these approaches.

Finally, in this study we have focused on how a shift in building practices may influence energy consumption but many perspectives are possible. One of these is how cash flows change and how they are allocated over time and between relevant actors. In tenant-owned housing, do developers save on construction costs by replacing communal laundry rooms with in-unit appliances? What is the alterative cost for the communal laundry room space? What is the value of in-unit appliances and do total revenues increase by being able to offer in-unit appliances? Do households loose or benefit financially from having in-unit appliances and how is life cycle costs impacted by choosing more efficient appliances? Especially interesting are the cases in which developers install a communal laundry room despite installing in-unit appliances, since, in those cases, residents pay for double access. In rental housing, in addition to the examples of in-unit appliances, housing firms have increasingly started to charge tenants per laundry slot instead of including a standard flat rate charge in the rent. In this way, incentives are created for tenants to reduce their laundering, without individualizing it. Based on this observation, it would be interesting to study how the life cycle costs for operation and maintenance are spread out and allocated for housing firms and tenants with communal and/or in-unit appliances.

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Author Contributions

Lena Borg conducted the on-site collection of data. The authors equally contributed to the design of study, analysis of data and writing the paper. Both authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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BEST PAPER AWARD FOR THE SUSTAINABLE REAL ESTATE AT THE AMERICAN REAL ESTATE SOCIETY (ARES) CONFERENCE 2012

Sustainable real estate

An empirical study of the behavioural response of developers and investors to the LEED rating system

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Abstract

Purpose – The purpose of this paper is to explore the notion of sustainability and research reporting price premiums for LEED-certified buildings.

Design/methodology/approach – This paper explores the notion of sustainability and research reporting price premiums for LEED-certified buildings. The durability of certification levels is explored by converting projects developed under the initial NC2-series system to a new vintage rating adopted in 2009. This conversion is made by applying Lagrangian multipliers to model stochastic impacts.

Findings – The study reveals that 18 percent of 591 projects developed under the NC2-Series were "misclassified" in terms of certification levels when converted to new NCv2009 standards. To the extent the market has pursued LEED certification levels, the unanticipated changes may have led to the adoption short-term solutions that are inappropriate due to the long-term nature of real estate assets.

Research limitations/implications – Given the complexity of the LEED rating system, it is unknown how the market will react to the lack of durability and approach pricing over the long-term.

Practical implications – The results indicate market participants should adopt a proactive approach to LEED certification.

Originality/value – The study identifies significant dynamics in the LEED certification system for new construction and behavioural responses that have not been reported in the literature.

Keywords LEED, Sustainability, Complexity, Green building, Behaviour, Real estate, Sustainable development

Paper type Research paper

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Introduction

In the USA interest in sustainable development has dramatically increased over the past decade. Indeed, for many designers, developers, investors and users the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a product of the US Green Building Council (USGBC) and has become an industry standard. From a behavioural perspective, this widespread acceptance can be explained by a number of factors ranging from a commitment to environmental awareness to a desire to capture higher risk-adjusted returns on investments. This latter claim has been supported by a number of papers that reported LEED-certified projects have traded at significant premiums compared to other projects. While such research has been welcomed by the market, little attention has been focused on the long-term picture and how behavioural responses of developers have responded to changes in the LEED rating system. Furthermore, researchers have not explored the durability of value premiums which is of paramount importance to investors. This question is especially important due to the significant modifications that have been made to the LEED rating system. From a technical perspective, these changes are understandable as the USGBC has made it clear that it will continue to enhance the LEED rating to take advantage of new materials, systems and knowledge that have emerged during the diffusion of innovation process. While the commitment to continuous improvement is understandable in terms of efficacy from a performance perspective, it may have unintended consequences from an investment perspective as it creates a moving target and adds a level of uncertainty that can affect values over time.

This paper explores the stability or reliability of the LEED rating system over time. It should be noted that this line of inquiry is not intended to criticize the efforts to improve the performance of buildings in an effort to reduce the environmental impact and create a better built environment. Rather, the objective of this paper is twofold. The first objective is to explore the behavioural side of the equation, focusing on how designers and developers pursued certification levels under the initial set of LEED rating standards (i.e. the NC2-series or vintage). The second objective is to determine how durable those certification levels were in light of changes that were made to the LEED system when the new NCv2009 system was rolled out. The empirical analysis includes a systematic analysis of the individual attributes in each of the categories of credits that were used by producers of space to achieve various levels of certification (e.g. certified, silver, gold and platinum) to rate projects. In addition the pattern of credit distributions around the breakpoints between levels will be analysed to provide insights into the behaviour of space producers. Of particular interest is whether developers targeted minimum certification levels and slightly overshot the breakpoints to provide a moderate cushion in case some credits were lost. While this strategy could help constrain costs, it would make the designations vulnerable if changes in weights of the six impact categories comprised of 71 individual attributes for earning credits occurred as the underlying rating system was revised. This question will be empirically analysed by converting the NC2-series project level credits and resultant certification levels to the NCv2009 vintage rating system. These changes will be applied to 591 individual projects to determine how many would have received a different certification level had the new standard been in place when they were first certified.

The underlying questions addressed in this paper reveal a conundrum for the industry; whether it is more important to stabilize a rating system such as LEED, or whether it is more important to introduce continuous change in pursuit of greater environmental sensitivity. It also points to the economic complexity of placing a value on LEED certification levels or other systems which are subject to added uncertainty on top of traditional drivers of value. To help set the stage for the empirical investigation of the impact of changing LEED rating systems, we begin with an overview of the notion of sustainability as seeking long-term parity across generations. This approach was specified in the Brundtland definition established by the WCED (1987) and modeled by Grissom (2005). This discussion highlights the importance of sustainable development practices and notes that, as stewards of the land we have tremendous social responsibility to make scarce resource allocations with special emphasis on the longitudinal nature of the underlying real estate over time and periodic regimes. This theoretical perspective will be complemented by an analysis of several contemporaneous surveys of various real estate professionals. These surveys provide insights into how the market approached sustainability and LEED certification in the early stages of growth, as well as how those responses have changed over time as the market has matured. We conclude with a discussion of the possible implications of our findings in light of market inefficiencies, market cycles and complexity economics that are amplified by the behavioural nature of real estate as it relates to achieving user equity and consistency over time.

Background

Over the past decade, interest in "sustainable real estate" has experienced tremendous growth. Despite this interest, there is little consensus as to what the term actually means. Thus, before delving into the major research question addressed in the article, it is useful to begin with some preliminary comments. Briefly, there are two critical dimensions of real estate that should be considered in any discussion of sustainability: space time and money time. That is, real estate has a temporal dimension that affects its spatial side, as well as its "capital" or money side. Since real estate improvements – both to a site and on a site in the form of buildings – are resource intensive, the deployment of such resources must be compensated. Since this compensation will come from the market or from public sources, the decision to use real estate must provide an adequate return to justify the investment of resources. On the public side, this "return" may be intangible, or may come as part of the government's responsibility to provide amenities needed to serve residents or, in many cases, taxpayers who have a vested interest in how public funds are deployed. On the private side, this return can have some "intangible elements" as in the case of pride of ownership, but ultimately must still have sufficient "tangible" or economic benefits to provide an adequate return on investment of capital.

Graaskamp employing a normative standard of high social consciousness in land use economics, which predated the current paradigms of sustainability, focused on real estate as a precious resource. This normative tradition developed in the Wisconsin tradition of land economics originating with Richard T. Ely helped define a positivist empirical link between urban property and social problems. This association was pointed out by Ratcliff (1972) who stated:

> [. . .] that the area of the social sciences concerned with urban economics and urban land will respond to the merging nature of urban problems. After all, social scientific effort would be pointless if it did not serve in solving social problems and in the advance of social well-being [. . .] I am sure that you share with me a constant exposure to writings on the urban crisis, ad infinitum, ad nauseum. Since most people now live in cities, the urban crisis is essentially co-extensive with the social crisis [. . .] (p. 7).

Graaskamp provided a foundational link of these issues relative to sustainable real estate by trying to sensitize his students and professional audiences to the need to approach real estate decisions as resource management issues. He summarized his sense of social commitment regarding real estate rather elegantly in a television interview he granted toward the end of his career reprinted in Jarchow (1991):

> Man is the only animal that builds his terrarium about him as he goes and real estate is the business of building that terrarium. So we have a tremendous ethical content, tremendous social purpose. The student is looking for a field in which entrepreneurship and a way of life can be integrated into social purpose. We like to argue that the entrepreneur of tomorrow is going to be the individual who can inventively implement social policy (p. 68).

Graaskamp recognized that real estate decisions should satisfy a high ethical standard in terms of future generations. He contended that real estate activities and projects could be treated as cash cycle operations that link the spatial and economic dimensions over time. This insight was one of the driving forces behind the development of discounted cash flow (DCF) analysis using computer technology that he pioneered in the late 1960s. It also explained the emphasis that he placed on developing a better understanding of the economic assumptions of the respective parties about future operations and market conditions. He argued for a responsible approach to real estate development, which if followed, would have helped the market avoid much of the real estate crisis that surfaced in the latter 1980s and is occurring once again in the current market. He stated that:

> Real estate development also is a complex, collective process, not only accommodating an activity within the parcel, but also adapting to the context of the specific surrounding environment, involving different personalities and interest groups as well as limited resources. The political and social processes required to produce a real estate product must consider a diversity of impacts to find equitable reconciliation between who pays and who beneftis (p. 112).

In retrospect, he was arguing for "sustainable use," and added the notion of cash solvency to create an early version of the now-familiar "triple bottom line" of people, planet and profit. It is important to note that the profit dimension embedded in this definition takes on a longitudinal perspective. That is, the true test of sustainability is the ability to satisfy this proposition over time; to provide a durable solution that is appropriate for use decisions which constitute an "irretrievable commitment" of scarce resources. This temporal nature operates on both the spatial (i.e. supply/demand for product) front as well as on the capital (i.e. supply demand for investments) front. Thus, on the spatial side, to create a project with sustainable demand, it is critical that the developer produce a project for which there is "effective" demand for the particular real estate offering over the full life cycle of the property. This long-term perspective is particularly important due to the "durable" nature of real estate which mandates that the true test of sustainability is determined over time and is reflected in continued market demand, both now and in the future. With this added criterion, a working definition of sustainability on the spatial front offered by DeLisle (2008) is:

> The use of scarce real estate in an efficient, economic, equitable and socially responsible manner that provides an acceptable – if not optimal – fit between users of space and the space that is produced that has an existing and enduring effective demand and balances the needs of current and future generations.

DeLisle (2008) establishes several evaluative criteria for determining sustainability. They are: efficient, economic, equitable and socially responsible uses, which in turn achieves goodness-of-fit between users and space; satisfies current and future demand for space; and balances needs of current and future generations Since these spatial benefits focus on space users and space produces, it is useful to review some of the drivers attracting some of the early adopters to the "diffusion of innovation" process related to green buildings. Based on a series of surveys of corporate users, developers and investors conducted by DeLisle between 2006 and 2008 to understand their attitudes and behavioural responses to sustainability, found the operating benefits of:

(1) Competitive advantage:
  - first mover advantage in reputation and brand;
  - potential to create a better work environment and enhance productivity; and
  - deliver positive marketing and goodwill as customers demand green practices.

(2) Spatial impacts:
  - improved performance and operations of investments and facilities; and
  - produce more comfortable building for tenants and more efficient operation lowering costs.

(3) Environmental benefits:
  - deliver positive environmental, ecological and sustainable effects;
  - reduce use of non-renewable resources; improved energy savings; and
  - contribute to carbon reduction, waste reduction.

In addition to this primary research, the literature is replete with articles discussing the benefits of green buildings at the spatial level. For example, Singh *et al.* (2011) explored the costs and benefits from improved indoor environmental quality (IEQ) in LEED-certified buildings. Using case studies, he explored the requisite incremental hard and soft costs and estimated the resultant benefits to space users in terms of well-being and productivity. He collected well-being and productivity data from employees who occupied non-LEED offices and then followed up after their move into LEED offices. Applying a Life Cycle Cost model, he concluded that the gains of IEQ improvements offset the costs and were economically viable investments. On a similar note, Temmink (2010) noted that corporate users approached sustainability as a business imperative:

> [...] as a result of changing energy prices, anticipated carbon regulation, stricter future building codes, cost containment, limited natural resources, or increasing pressure from stakeholders, the question has clearly changed from whether sustainable design should be considered to why one would choose not to consider it.

On the capital side of the equation, sustainable investment must provide competitive risk-adjusted returns over the full investment cycle. In terms of investment analysis, the determination of whether this criterion is likely to be satisfied is typically based on some form of net present value (NPV) or the internal rate of return (IRR) generated through some type of DCF analysis. Both of these measures consider periodic cash flows and future sales proceeds. Figure 1 shows the life cycle of an investment. As noted, the NPV is the present value of the periodic cash flows plus the present value of the net sales proceeds at the end of the holding period at some specified discount rate (R):

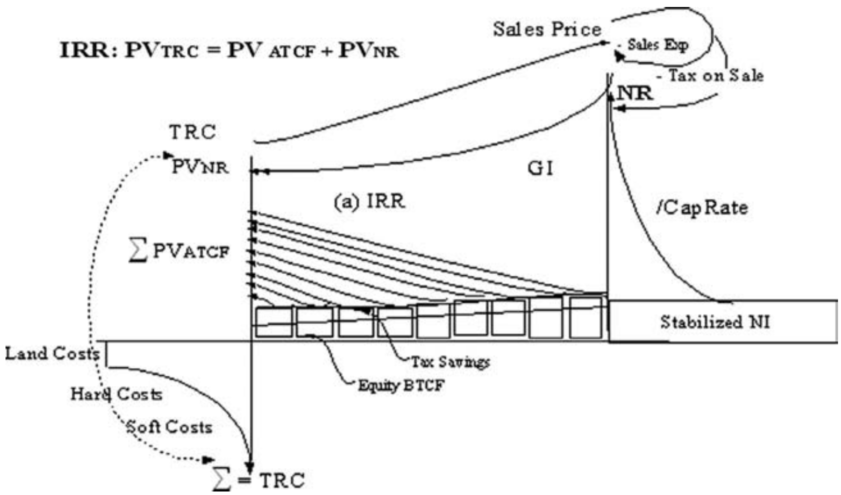

Figure 1.
DCF model

$$NPV = \sum [PV(ATCF_{1 \geq n})_R + PV(NR_n)_R] - EQ_1$$

In a DCF model, the IRR is rate at which the present value of the benefits equals the present value of the outlay:

$$\sum (PV(ATCF_n) + PV(NR_n)) = PV(EQ_1)$$

where:

ATCF = after tax cash flow/period 1-n periods.

NR = net reversion after tax.

EQ_1 = initial equity investment.

At a simplistic level, the appropriate level of equity investment (EQ_1) can be estimated by applying a going-in cap rate (R) to the expected net income, while the net reversion can be estimated by applying an exit-cap rate to the stabilized net income expected at the time of sale. This relationship is reflected in Figure 2 which identifies some of the key areas in which sustainable properties can enhance property value. As noted, some of the impacts of developing sustainable properties increase total replacement cost (e.g. higher land costs, higher material costs, higher labour costs, greater time to market) which show up to the left of the market value/cost *y*-axis. On the other hand, some elements associated with sustainable buildings in theory, and partly reinforced by preliminary research, can enhance or increase market value (i.e. the present value of future benefits).

As noted, some of these elements affect the net income that can be generated (e.g. rent premiums, lower operating costs, higher occupancy rates) while others affect the net reversion (e.g. exit-cap rate, expected NI). Finally, if sustainable buildings have a durable value proposition, this may constitute lower risk which could translate to a lower yield requirement in terms of the discount rate applied in NPV analysis or the IRR hurdle rate, both of which would increase the present value of benefits (i.e. market value). On the other hand, if these benefits are not realized or are not stable, the value

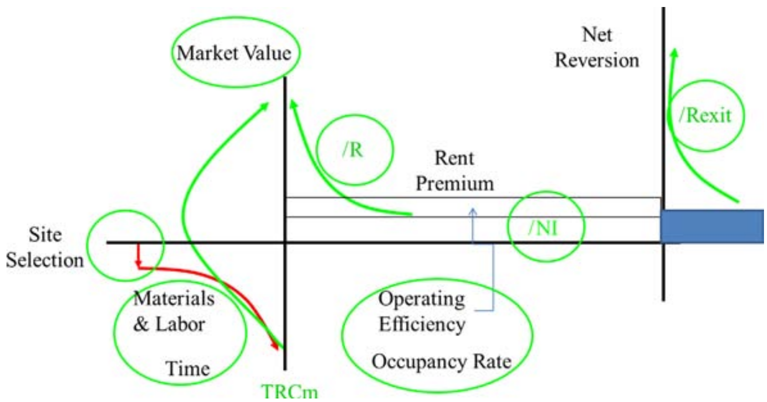

Figure 2.
Sustainable value proposition

proposition would not be durable subjecting a property to a "correction" when the market recognizes the risks or uncertainty.

In summary, from an investment perspective, sustainability hinges on the levels of net income and the required rates of return for a project which are related to the relative risk or uncertainty of an investment and the commensurate hurdle rates of return the market will demand to compensate for risk. Thus, if LEED designations are expected to increase net cash flows, reduce risk and/or attract capital with lower return requirements, these designations should add to the market value of a property and lead to premium pricing over otherwise comparable but non-designated properties. If these benefits are not maintained over time, this premium can be quickly eroded which translates to a lack of "sustainable" pricing/performance.

A number of articles, research reports and white papers have emerged which tout the positive value premiums associated with LEED designations. For example, an early study of the investment benefits that received significant attention reported that LEED-certified projects and Energy Star projects commanded higher rents and traded at a premium relative to other investments (Miller *et al.*, 2010). While these preliminary results are interesting, there is some concern whether they are "sustainable." That is, in many cases, the early pricing for LEED projects was based on an expectation that they would provide superior performance rather than on the basis of empirical research. The results of the Miller study received significant attention, including an article by Muldavin (2008), who provided an in-depth critique of the research.

In a recent paper, Fuerst (2009) used hedonic models to calculate a sale price premium for Energy Star and LEED labelled office buildings of 18 and 25 per cent, respectively. For properties that carried both designations, the sale price premium for dual certification was estimated at 28-29 per cent. Jackson (2009) reported even more startling results. He applied Monte Carlo simulation analysis to estimate the expected return and risk associated with LEED and Energy Star ratings with respect to the LEED designation, he isolated an average IRR of 126 per cent, with only a 10 per cent probability of achieving an IRR of 50 per cent or less. With respect to Energy Star certifications, he estimated an average IRR of 140 per cent, with only a 1.6 per cent chance of an IRR that was less than 50 per cent.

In a white paper targeted to institutional investors, Nelson (2007) noted the green buildings were altering real estate market dynamics:

> [. . .] the nature of product demanded by tenants, constructed by developers, required by governments and favoured by capital providers. The upshot will be a redefinition of what constitutes Class A properties and even institutional-quality real estate (p. i).

He went on to argue that " [. . .] property owners will need to adapt quickly – or risk the consequences of sharply shrinking demand for property that, over time, becomes increasingly obsolete." (p. ii) In an article directed toward appraisers, Pitts and Jackson (2008) recognized the growing pressure on appraisers to consider the effects of green building in valuing properties. Despite the popular appeal of such a movement, they properly noted that such a change in valuation practices must be based on market evidence of enhanced value that can be attributable to sustainable components. While they recognized that there is a growing body of anecdotal evidence that such benefits are real, they noted the degree to which these green initiatives impact value will vary by property type, location, and local market conditions and is not easily teased out of the market data. This debate is likely to heat up even more as the commercial real estate market continues to recover from the financial and economic crisis affecting investors across the globe.

LEED overview

Types of LEED rating systems

During the early 2000s, the LEED Green Building Rating System enfolded a number of discrete systems: commercial interiors (CI), core and shell (CS), existing buildings (EBs), and new construction (NC). Each of these systems was unique and had its own sets of credits and impact categories. In general the systems were targeted for different situations including:

(1) LEED CI:
- for high-performance green interiors (healthy, productive places to work, are less costly to operate and maintain, and reduce environmental footprint); and
- for tenants and designers, who do not control whole building operations.

(2) LEED CS:
- covers base building elements (structure, envelope and building-level systems); and
- recognizes division between landlord and tenant.

(3) LEED EB:
- performance-based benchmark for building owners and operators to measure operations, improvements and maintenance; and
- seeks operational efficiency while minimizing environmental impacts.

(4) LEED NC:
- NC and major renovation green rating system; and
- designed to guide and distinguish high-performance commercial and institutional projects, with a focus on office buildings.

Figure 3 shows the number of individual projects that were awarded LEED certification for each of the LEED systems. As noted, with the exception of CS, each of the systems has exhibited dramatic growth, mirroring the early growth phase of a typical product life cycle. The most dramatic growth in the number of properties has been in the

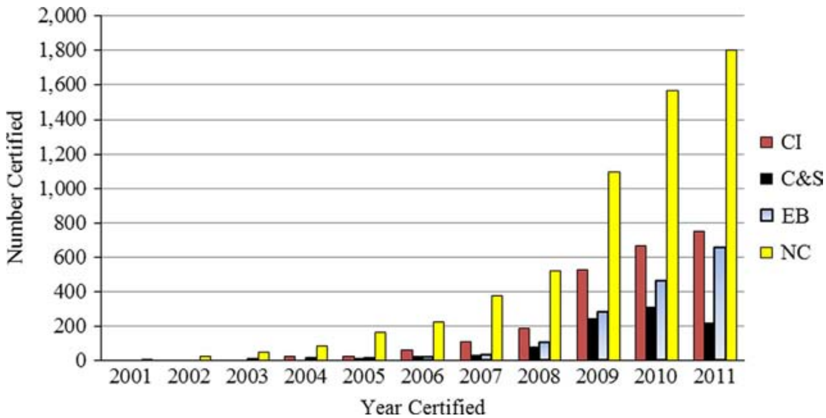

Figure 3.
Total number of certified projects by LEED system

NC system. The moderate decline in the rate of growth is likely due to a lagged cyclical effect as the pipeline of projects that decelerated as a result of the downturn as the commercial real estate market hit an inflection point in 2008 (Grissom *et al.*, 2012; DeLisle and Grissom, 2011).

LEED certification process

The process for achieving LEED certification begins with LEED registration and culminates in certification decision. Since the LEED systems are all based on attainment of a "to-be-built" project rather than aspirations at time of registration, the certification levels were not awarded until the projects were completed and inspected. Since the awarding of credits involves some qualitative dimensions and judgements that are rendered after the fact, there is no guarantee that credits that were being pursued would be awarded. From a risk management perspective, to ensure that a certain targeted level was achieved, there was a need for some type of backup plan. In some cases, this translated to the conscious pursuit of more credits than needed to provide some "degrees of freedom". In other cases, a designer/developer would have to adopt a "back-up" plan which identified other credits that could be pursued to compensate for lost credits. This approach could be expensive since it would involve "change orders" and trigger unexpected costs that would be more difficult to pencil out the later they were addressed in the design/development process. This dilemma has created a number of behavioural implications and increases the complexity of the LEED system. For example, a risk-averse design/development team would seek a higher credit total up front. On the other hand, a risk-taker would shoot for the actual breakpoint of credits for the desired certification level to avoid unnecessary expenditures. These behavioural responses will be explored in the empirical section of this article.

One of the hallmarks of the LEED systems was the awarding of different levels of LEED certification based on credit accumulation. For example, there were four distinct certification levels for the LEED New Construction NC2-series. Presented in order of attainment, these included certified, silver, gold and platinum. As noted, a project would have to earn over 38 per cent of the total 69 credits in the NC2-series to be "certified," the lowest certification level. On the other hand, a project would have to earn over 75 per cent of the possible credits to achieve the platinum certification level (Table I).

While the awarding of credit differed among the LEED systems, each of them adopted the same nomenclature with respect to certification levels. Table II provides a breakdown of the 13,381 projects that received LEED certification under each of the respective systems (i.e. CI, C&S, EB and NC). Panel A presents the number of projects earning the respective certification levels between 2000 and July 7, 2012 when the data were extracted from the USGBC web site. As noted in Panel B, gold was the modal certification level across each of the LEED systems with 40 per cent (±) of projects falling in that category. On the other hand, only 6 per cent of projects achieved the highest certification level, while 21 per cent achieved the lowest (the Bronze category was dropped in 2000). The NC system was the dominant LEED system, accounting for 58 per cent, while CS accounted for only 8 per cent of projects (see: Panel C).

In addition to exploring the market in response to different LEED certification levels, it is useful to explore differences in market behaviour by owner type. Table III provides a summary of the number of projects achieving various levels of certification by owner type. As noted, profit organizations account for over half of all certified projects

Certification levels	Minimum credits	Percent of possible
Certified	26	38
Silver	33	48
Gold	39	57
Platinum	52	75
Total	69	100

Table I. Minimum credits/LEED NC2-series certification levels

Certification level	CI	CS	EB	NC	Total
Panel A: number by certification level by LEED system					
Bronze				4	4
Certified	468	95	406	1,639	2,608
Silver	827	293	570	2,512	4,202
Gold	953	401	670	2,797	4,821
Platinum	159	48	83	399	689
Total	2,407	837	1,729	7,350	12,323
Panel B: share of LEED system by certification level					
Bronze (%)	0	0	0	0	0
Certified (%)	19	11	23	22	21
Silver (%)	34	35	33	34	34
Gold (%)	40	48	39	38	39
Platinum (%)	7	6	5	5	6
Total (%)	100	100	100	100	100
Panel C: share of certification level by LEED system					
Bronze (%)	0	0	0	100	100
Certified (%)	18	4	16	63	100
Silver (%)	20	7	14	60	100
Gold (%)	20	8	14	58	100
Platinum (%)	23	7	12	58	100
Total (%)	20	7	14	60	100

Notes: [a]Through July 12, 2012; excludes LEED for homes

Table II. LEED certification level by LEED system 2000-2012[a]

Table III.
Number of certified projects by owner type and certification level

Owner type	Bronze[a]	Certified	Silver	Gold	Platinum	Total
Panel A: number by owner type by certification level						
Education		182	305	500	84	1,071
Government	3	465	969	1,123	132	2,692
Military		35	157	123	21	336
Non-profit		226	359	415	105	1,105
Individual		65	96	132	23	316
Investor		48	74	110	18	250
Profit org.		1,515	2,148	2,271	290	6,224
Other		72	94	147	16	329
Total	3	2,608	4,202	4,821	689	12,323
Panel B: share of owner type by certification level						
Education (%)	0	7	7	10	12	9
Government (%)	100	18	23	23	19	22
Military (%)	0	1	4	3	3	3
Non-profit (%)	0	9	9	9	15	9
Individual (%)	0	2	2	3	3	3
Investor (%)	0	2	2	2	3	2
Profit org. (%)	0	58	51	47	42	51
Other (%)	0	3	2	3	2	3
Total (%)	100	100	100	100	100	100
Panel C: share of certification level by owner type						
Education (%)	0	17	28	47	8	100
Government (%)	0	17	36	42	5	100
Military (%)	0	10	47	37	6	100
Non-profit (%)	0	20	32	38	10	100
Individual (%)	0	21	30	42	7	100
Investor (%)	0	19	30	44	7	100
Profit org. (%)	0	24	35	36	5	100
Other (%)	0	22	29	45	5	100
Total (%)	0	21	34	39	6	100

Note: [a]The bronze category was phased out in early 2002

but have a higher concentration in the lowest "certified" category. In terms of levels, gold certification is the most common type of certification, with education, investors and "other" having a higher percentage concentration than average as observed in Panel C. Panel C also shows that in terms of platinum certification, investor owners, educators and individuals have greater concentrations than the other categories, with government showing a 1 per cent lower rating than profit organizations.

LEED impact categories and attribute credits

Under each of the various LEED systems (i.e. CI, C&S, EB and NC), credits are assigned to projects that satisfy certain evaluative criteria. Since LEED for NC is the most commonly adopted LEED system and has accounted for some 58 per cent of market activity, it is useful to focus on that system to avoid unnecessary complication. Table IV provides a breakdown of the LEED NC2-series rating system. As noted, there are 69 possible credits for attributes spread among six impact categories. Since the credits were additive, the greatest weights were applied to energy and atmosphere (25 per cent), IEQ (22 per cent), sustainable sites (20 per cent) and materials and resources (19 per cent).

Impact categories	Impact code	General areas of interest	Maximum credits	Share (%)
Sustainable sites	SS	Construction activity, site selection, transportation, site development, storm water, heat island effect, light pollution	14	20
Water efficiency	WE	Water efficient landscaping, wastewater management, water usage	5	7
Energy and atmosphere	EA	Energy systems, performance, renewable on-site, commissioning, refrigerant, green power sources	17	25
Materials and resources	MR	Recyclables, building reuse, construction waste management, material reuse, recycled content, regional materials, certified wood	13	19
Indoor environmental quality[a]	IEQ	IAQ performance, tobacco smoke, air delivery, ventilation, construction IAQ plan, low-emitting materials, indoor chemical and pollutant source, controllability of systems, thermal comfort, daylight and views	15	22
Innovation and design	ID	Exceptional performance, design and/or innovation in new categories or attributes, LEED accredited professional	5	7
Total			69	100

Note: [a]Initially referred to as "indoor air quality" (IAQ)

Table IV.
LEED NC2-series categories, weights and credits

Less weight was attached to water efficiency (7 per cent) and innovation and design (7 per cent). As noted, each of these impact categories addressed a number of individual attributes covering several areas of interest. In several categories, projects had to satisfy attribute prerequisites to earn any credits. In addition, some categories provided additional credits for different levels of attainment. For example, in materials and resources, a project that had 10 per cent or more recycled content received one credit, and an additional credit if it hit 20 per cent or more.

Temporal lag and LEED dynamics

In addition to forcing design/development teams to make some strategic decisions regarding how to achieve targeted certification levels, the practice of determining certification levels after project completion introduces another level of complexity to the process. This complexity emanates from the fact that during the potentially considerable time lag between project inception and project delivery, new "best practices" may emerge. This is particularly likely during the early diffusion of innovation process where new materials, methods and practices are being discovered as the market struggles with the early growth phase. The emergence of new materials, methods and practices is a natural occurrence during the early phases of the diffusion of innovation process. This is especially true in real estate as was experienced during the energy crisis of the early 1980s which created a spurt of interest in energy efficiency (DeLisle, 1984). During that period, uncertainty and instability of an emerging technology inhibited market acceptance of energy efficient systems.

In the case of LEED systems, the temporal lag created an added risk in the form of changes to the underlying rating model. This occurred between 2000 and 2005 when the LEED NC2-series went through a number of enhancements and modifications. While understandable in terms of the desire to take advantage of knowledge creation that emerged in the field, the changes added to the complexity of the process. This complexity had a significant impact on market behaviour. For example, the overlapping standards and relatively steep learning curve early on resulted in lagged adoption of innovation to help mitigate uncertainty and risk. In addition, the introduction of continuous quality improvement effectively mandated that designers and developer proactively monitor the LEED rating systems for proposed and actual changes in standards. Finally, since the standards combined quantitative and qualitative elements, designers had to monitor project credit interpretation rulings (Project CIRs), which provided official answers to technical questions about how to implement LEED.

The end result of the series of modifications to the LEED NC2-series was the creation of a sustainable building rating standard that was actually a "dynamic" as opposed to a static or fixed standard. To those outside the LEED network, the dynamic nature of the standards created uncertainty and complexity. However, to those immersed in the professional network, it was endemic and noted with. Indeed, one of the underlying goals of the LEED certification is to encourage innovation, to identify new materials, methods and processes for enhancing sustainability. This dynamic element was explicitly built into the rating system through the inclusion of a category of credits that were awarded for "innovation and design process." As explained in the LEED NC 2.2 manual (2005), the objective of this category is:

> To provide design teams and projects the opportunity to be awarded credits for exceptional performance above the requirements set by the LEED for NC Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED for NC Green Building Rating System (p. 77).

When credits are awarded under this category, the underlying "innovations" are documented and promulgated among LEED members and the broader market. Over time, some of the more successful innovations become "best practices." In some cases, the innovations become institutionalized and were incorporated in modifications to the LEED rating standards.

To account for changes that may occur during the time lag between project registration and project completion, USGBC provided a transition period during which designers may select the vintage system under which a project will be rated. While this accommodation was necessitated by natural inefficiencies built into the real estate design and development processes, the end result was an added level of complexity due to the existence of overlapping time periods during which a project can achieve certification by meeting differing requirements. Table V provides a summary of the number of projects certified under various versions of the LEED NC 2.0, 2.1 and 2.2 versions which for purposes of clarity is denoted LEED NC2-series. As noted, three distinct but related versions of LEED NC2 were in place between 2000 and 2005.

The relative numbers of projects certified under the three distinct but related series provide several insights into market behaviour. First, the adoption of each of the NC2 versions reflected a diffusion of innovation curve beginning with gradual adoption and then rapid acceleration as the market became more familiar with the standards. The pattern was repeated as the next version was phased in and the previous one was

Year	Number per year by NC2 version				Annual share by NC2 version			
	NC2	NC2.1	NC2.2	Total	NC2 (%)	NC2.1 (%)	NC2.2 (%)	Total (%)
2000	1			1	100			100
2001	4			4	100			100
2002	16			16	100			100
2003	42			42	100			100
2004	61	23		84	73	27		100
2005	65	96		161	40	60		100
2006	55	168	1	224	25	75		100
2007	27	315	33	375	7	84	9	100
2008	16	332	172	520	3	64	33	100
2009	4	277	811	1,092	0	25	74	100
2010	4	159	1,385	1,548	0	10	89	100
2011	1	78	1,482	1,561	0	5	95	100
2012		41	697	738		6	94	100
Total	296	1,489	4,581	6,366	5	23	72	100

Table V.
Number certified under NC 2.0-2.1-2.2 series

phased out. Despite this shifts in market share among the three NC versions, at an aggregate level the number of NC-certified projects continued to increase, peaking in 2011. Second, designers and developers were simultaneously delivering NC-certified projects that adhered to three sets of standards. While these standards were fairly consistent through the entire LEED NC2-series, the three versions were differentiated by a number of modifications, clarifications and enhancements. Adding further complexity, in some cases new standards were retroactively made available to projects that registered under previous standards. This was explained in a memorandum from USGBC staff (2006) which stated:

> Based on feedback from LEED project teams and users following the launch of the LEED refinements in November 2005, it became clear that credit modifications and compliance paths that were balloted for v2.2 were also appropriate and should be made available for use in v2.0/2.1 projects, with certain limitations. USGBC thus developed the attached matrix that establishes linkages between v2.2 credits that can be used by v2.0/2.1 projects (p.1).

While the changes in the LEED NC2-series were fairly benign, the big “fix” occurred with the conversion of the LEED NC2-series to the LEED NCv2009 vintage system. Interestingly, the LEED® for NC 2009 was put out “For 1st Public Comment” in 2005 which signalled a major change was coming to the LEED NC project rating system. Despite that signal, the market was free to elect which of the two vintage LEED NC systems they would adopt for certification. The behavioural response was as expected, with some projects adopting the more familiar standards. This response was understandable in light of the relatively steep learning curve for the design and construction process that some professionals and companies had overcome. Indeed, during this period some developers claimed that the 5-10 per cent premium cost of adoption that was incurred in the earlier years had been reduced to a nominal amount. This was especially true for projects that were pre-planned for LEED designations and as economies of scale for new materials and methods were achieved. The end result was a significant overlap between availability of the two competing classification systems.

Figure 4 compares the number of projects earning LEED for NC designations under each of the two systems. As noted, the LEED NC2-series experienced modest growth through 2006 relying on "early adopters" to help make the market. The rapid growth phase of the life cycle began in 2007 and peaked in 2010. On the other hand, early adoption of the NCv2009 occurred 2009-2010 and then "accelerated" in 2011 despite the downturn in the commercial market. Interestingly, in 2011 the NC2-series still dominated the new series although the market share had begun to shift. For the first half of 2012, the two vintage systems were about equal in terms of market share.

LEED NCv2009 vintage changes

There were a significant number of changes between the NC2-series and NCv2009 vintages. Table VI presents a summary of the major changes operating between the two systems of classification. This includes:

- *Credit totals*. The NC2-series consisted of 69 credits while the NCv2009 system included 110 credits. As noted in the addendum, for the most part the two vintages use the same attributes with the differences stemming from changes in the number of credits assigned to various attributes.
- *Impact category weighting*. The change in the number of possible credits and the breakpoints between the various levels of certification constituted a change in the relative contribution of the impact categories (i.e. weights). For example, the first three of the original six impact categories (i.e. sustainable sites, water efficiency, and energy and atmosphere) received added emphasis by comprising a greater

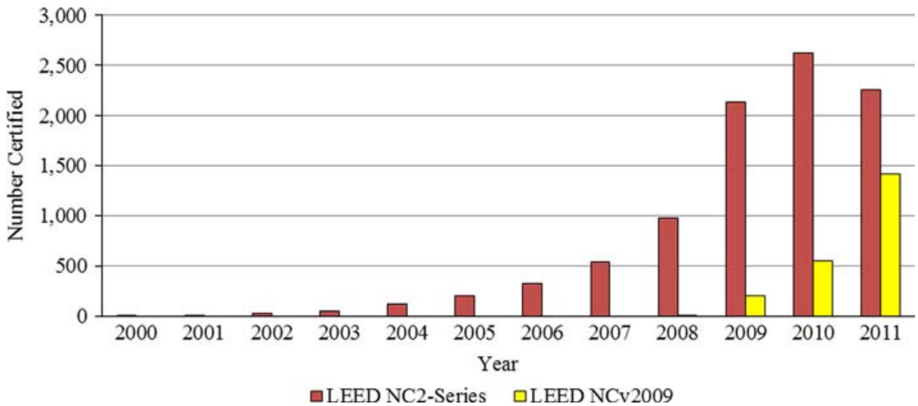

Figure 4.
Number certified by year by vintage LEED NC2-series and NCv 2009

Table VI.
Comparison of vintage NC2-series and NCv2009

LEED impact categories	Possible credits 2005	Possible credits 2009	Share of credits 2005 (%)	Share of credits 2009 (%)
Sustainable sites	14	26	20.3	23.6
Water efficiency	5	10	7.2	9.1
Energy and atmosphere	17	35	24.6	31.8
Materials and resources	13	14	18.8	12.7
Indoor environ. quality	15	15	21.7	13.6
Innovation and design	5	6	7.2	5.5
Regional priorities	0	4	0.0	3.6
Total	69	110	100	100

share of the total credits, while the latter three (i.e. materials and resources, IEQ, and innovation and design) received less emphasis due to a decrease in the share of total credits.

- *New regional priority impact category.* In addition to changing the credits assigned to the existing six impact categories, the NCv2009 classification standards added a new impact category entitled "regional priorities." Prior to this change, the evaluation of all projects was standardized, treating all projects equally regardless of where they were physically located. As noted in Figure 5, the adoption of LEED certification was geographically dispersed among the eight geographic regions delineated by the National Council of Real Estate Investment Fiduciaries (NCREIF, 2012). As might be expected, given the vast expanse of the USA there were significant differences among regions in terms of weather patterns, resource constraints, landform and other attributes. As such, a standardized approach to ratings could create incentives that were inappropriate and/or counterproductive in terms of "sustainability." To address this issue, the NCv2009 operations created a new impact category entitled "regional priorities." These priorities differed by geographic region and could account for up to four of the 110 credits that could be earned under the new system.

To help with the transition between the LEED NC2-series and NCv2009, a tremendous number of collateral materials were generated by USGBC (2005a, b, c, d, 2006a, b, 2007, 2008a, b, c, 2009, 2010, 2011a, b). These included a series of seminars, training sessions, how to guides, conversion worksheets and other proprietary materials. In addition, to provide technical guidance on implementing LEED, the Project CIRs for the NC2-series were supplanted by LEED interpretations. In addition to addressing changes introduced in the NCv2009 system, LEED interpretations were:

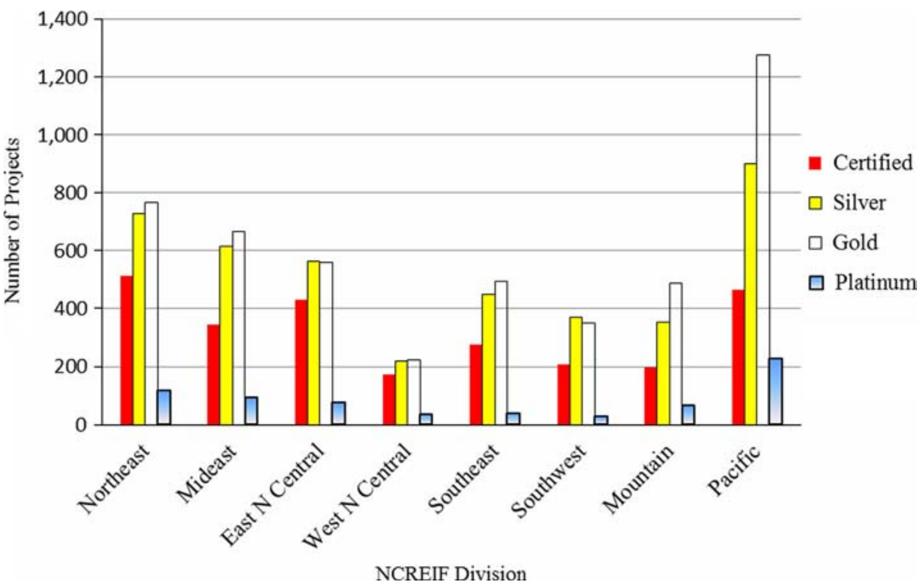

Figure 5.
Geographic dispersion of LEED NC projects by NCREIF division

- explicitly designed to be precedent-setting;
- were published on-line; and
- were subject to consensus-based review by member-selected, volunteer committees.

In addition to greater convenience, the on-line element provided greater transparency since unlike Project CIRs, LEED interpretations were searchable and were available to the public versus members-only. Despite these efforts to promulgate the new LEED NCv2009 vintage system, the extensive nature of the changes created uncertainty and added to the complexity of adopting, implementing and pricing LEED-certified projects. It also added to the already steep learning curve which created a formidable barrier to entry for non-LEED certified market participants. This challenge was recognized by virtue of the fact that a project could earn 1 credit by retaining a LEED-certified professional.

Empirical analysis of the durable value proposition

Problem statement

A number of researchers have reported discovering price premiums for LEED-certified projects, the relatively limited period of time during which a significant number of certified projects have sold reveals a relatively short track record. While a natural by-product of the introduction of a new standard, the short historical frame presents a number of challenges for researchers trying to determine whether any reported price premiums are a temporary artefact, represent a cyclical phenomenon, or represent a structural change. The answer to this question is of paramount concern to institutional investors and advisors who are held to a high fiduciary standard. For such players and for others approaching real estate as a long-term investment, performance results extracted from such a limited time frame cannot be accepted at face value, but must be considered somewhat speculative as is appropriate during the exploratory phases on new innovations. This is especially true in light of the cyclical nature of the real estate market and the fact that these projects have not yet been tracked across a full business cycle. Thus, while the results of individual studies have reported the capturing of price premiums in LEED-certified projects these observed premiums may short-term benefits and not durable or sustainable over the long term.

The need to approach previously published research that found significant price premiums for LEED-certified buildings from a cautionary stance is amplified by the fact that the LEED designation standards are in a state of flux, with major revisions being introduced at relatively short intervals. The objective of the empirical portion of this paper is to explore this fundamental issue; to determine the impact of changing standards on the levels of designations and by extension, any market value premiums that may have existed up to the time of the revisions are likely to endure, or whether they may evaporate when the market begins to differentiate by vintage of certification.

From a public policy perspective, the continued evolution of LEED and/or other systems to rate the sustainability of buildings might appear to be positive public policy and may help advance the aggregate well-being of the community. While it might appear that designers and developers could rely on such tools to deliver more sustainable spatial solutions, the question remains whether the resultant value proposition that is established is durable and whether it meets this test on both the public and private side of the equation. In the case of real estate, this durability criterion dictates that the appropriate temporal frame for judging the success of a project is long-term and spans the full market cycle. Thus, in addition to furthering community and social values, on the for-profit side of the market such projects must provide market-based solutions for which there is sufficient current and future demand to generate net revenues at risk levels that are sufficient to maintain or enhance value. This dictates that the standards that guide the production of space be designed with an eye to the behavioural side of the value proposition in terms of future consumers of space and changing consumption preferences that affect demand and hence, value.

It is recognized that advances in best practices for green building can be used as a tactical tool to help improve the success of sustainable design and development outcomes. In this regard, Lewis and Howard (2003) acknowledge that encouraging the advancement of professional practices can lead to continuous "learning and improvement." LEED standards can contribute to such operational improvements over time. With this inferred association Lewis and Howard note:

> This is a time of massive and rapid change in the environmental practices of the U.S. building industry. Green buildings are a local point and a catalyst for these changes. Green technologies are evolving rapidly, leading to both improved cost effectiveness of green development strategies and increased acceptance of green building concepts in mainstream projects (p. 8).

They further suggest that the speed of this change calls for increasing rigor and sophistication in green building rating standards, but emphasize evolutionary process be considered rather than the revolutionary change advocated by some.

The question of whether changing sustainability standards should be relatively moderate or evolutionary, or more dramatic and revolutionary provides a number of has a number of strategic implications and is likely to create healthy tension in debates of when, how and how much to change standards. In the case of the LEED for NC rating system, the initial period of changes which guided the NC2-series reflected evolutionary change with a series of minor adjustments. With the introduction of the NCv2009 vintage system, the changes were more dramatic, albeit not sufficiently different to fall into the "revolutionary" category. Regardless of the degree of change in the rating standards over time, from a capital market perspective the lack of consistency associated with inconsistency in green building standards over time may have a deleterious impact on the "real estate value proposition." The underlying problem statement addressed in this paper focuses on this issue. More specifically, the absence of stability in LEED standards creates a degree of uncertainty which, by definition, increases the risk associated with real estate investment. To offset such risk, real estate investors would likely require higher returns (i.e. hurdle rates) which would place downward pressure on market values. Such changes could be material and could more than wipe out any temporary or short-term gain in value that could be attributable to LEED designations. This outcome is contrary to the findings of prior research and the fundamental structure of the complexity operating in the DCF/PV model shown in Figure 1 that is used to support the economic value premium associated with LEED compliance analysis.

The downward pressure on market values due to changes in LEED requirements is especially true if such changes result in a decline in designation levels for projects that were built to a now-obsolete standard. For example, assume an investor is willing to pay a premium for a building that has been designated as gold, the second highest category of designations. If significantly different standards are adopted as in the case of the NCv2009 rollout, it is possible that a building might slip down to a lower level of certification (e.g. silver). Indeed, such phenomena could occur as a result of moderate changes in standards if the behavioural response of designers and developers was to target minimum breakpoints for desired levels of certification, providing few degrees of freedom in the case of a change in credit awards. In both cases, if the premium price for a silver-certified building is lower than that for a gold-certified one, any premium price that was paid at the time of acquisition could be eroded and the investor would have lost his/her return. Even if the investor might hold the property for the long-term, such changes would represent "unrealized losses" that would have to be reflected in the valuation of "mark-to-market" holdings. This is often the case in real estate creating an unforeseen consequence that is difficult to measure for the investor.

Some might argue that since the existing designations are "grand-fathered" in the value losses are avoided. While intuitively appealing, such an argument does not hold up in the case of a real estate investment. For example, under professional appraisal standards, when valuing an EB, an appraiser must deduct for depreciation. One form of depreciation is "functional obsolescence" or the failure of a building to meet modern standards. As such, changing LEED standards would constitute functional obsolescence which, depending on the magnitude of changes, may or may not be economically viable to correct. Changing standards could also affect how the market positions a building, with some falling out of favour of the buyers and users interested in the features associated with the newer designation. Another form of "depreciation" which must be recognized in appraisal is physical obsolescence. This could occur where adherence to an industry standard fails to deliver the desired results over time. While related to functional obsolescence, this criterion addresses the "efficacy" of various criteria specified in a market/regulatory regime. Assuming there are some compelling reasons to change LEED rating systems to improve "sustainability," by definition non-compliant buildings could be expected to perform to a lower standard of efficiency as influenced by acceptable levels of market and user preferences.

A final concern with changing rating or designation standards relates to the confusion that might be introduced into the market. Depending on the importance of designations to buyers, the creation of an array of designations which cannot be easily interpreted without looking at the vintage or year of designation and, by extension, the underlying rating standards which they satisfied. This complexity and the resultant uncertainty is amplified by the fact that there is a significant transition period within which a new building can opt for one standard or the other. This makes it impossible to rely on the year of construction or completion to understand the standard of performance that might be expected from a designated building. While these issues are clear to real estate professionals, they are not as clear to policy makers and others not active in the real estate investment market. This lack of understanding of the investment side of the real estate industry was punctuated in the following quote extracted from a LEEDuser.com blog:

> [...] but you might be able to achieve a higher certification level (such as Gold versus Silver) by staying with a pre-2009 system. Usually, the system under which a project is certified is not as important to the owner and the public as the certification level (www.leeduser.com/compare#resources-tab).

The fundamental research question explored in this paper is whether projects certified at specific levels (e.g. certified, silver, gold and platinum) under the vintage NC2-series would retain the same level if converted to the NCv2009 system. The a priori hypothesis was that there would be significant changes in classification between the two vintages. This expectation was based on several considerations related to behavioural responses of early adopters. For example, responses to primary surveys of market participants conducted by the authors between 2006 and 2010 revealed that a significant share of early adopters of LEED certification were not attracted by the underlying economics or price premiums. For example, some were motivated by a "first to market" strategy while others sought to differentiate their companies from the broader market by making a public statement about their commitment to social responsibility. These "soft" or non-economic reasons were particularly important during the initial wave of LEED-certifications since marginal costs were high and economic benefits were speculative and based on good faith estimates that were inherently risky due to the absence of an established market on either the supply or demand side of the equation. The end result of these pressures was to evoke a likely behavioural response in which developers would pursue the minimum credits needed to achieve targeted designation levels. To the extent these behavioural responses occurred, they would manifest themselves in a series of leptokurtic curves (i.e. high concentrations just above the breakpoints between certification levels credits) with narrow confidence intervals and distributions that would be skewed and exhibit fat tailed extremes.

The strategy of slightly overshooting the target credit breakpoints to avoid the risk of limited market acceptance and demand, as well as to reduce development costs adds to the risk of reclassification in the event of changes to the rating standards. Projects with few degrees of freedom related to certification levels, even if a minor change in credit standards occurs could trigger reclassification. On the other hand, if there were significant changes in classification, then projects that appeared to be insulated from reclassifications could be in jeopardy. In such cases it could be presumed that observed price premiums would be quickly eroded and in some cases, might actually result in discounts due to functional obsolescence. While such analysis is beyond the scope of this study, the discovery of significant differences would suggest that the inherent complexity emanating from built-in dynamics in the LEED rating system may have resulted in mispricing in the market.

Research design

A multi-stage approach was adopted to explore the stability of LEED rating standards during the transition from the NC2-series to the NCv2009 classification. The first stage explored differences between the two standards to develop a comparison which could be used to track changes in the classification of projects certified under the NC2-series if they were converted to the NCv2009 vintage series. The second stage involved the primary analysis of individual buildings that were certified under the NC2-series. This involved manual entry of detailed credit accumulations across attributes for individual projects listed on the USGBC web site as if it were Fall 2008. During data development and scrubbing, the potential 800 or so projects were reduced to 591 usable projects. Once the data were stabilized, the projects were rescaled from 69 credit maximums to 110 maximums for the NCv2009 vintage system. These calculations were made on an item-by-item basis across the six impact categories. Finally, since the NCv2009 vintage included a new impact category labelled regional priorities, an adjustment to the scores was made to award the appropriate bonus credits.

Results of empirical analysis

Before converting projects from the NC2-series to the NCv2009 system, it is useful to explore some of the descriptive statistics that provide insights into market behaviour. Table VII provides a snapshot of the key statistics for the six impact categories for the 591 projects in the sample. The pooled data presented in Table VII include projects under the four levels of certification (e.g. certified, silver, gold and platinum). This project accounting information provides useful calibration, but offers limited market insights into how the impact categories factored into the individual levels of certification which is of particular interest in this study in which the hypothesized behaviour would exhibit credit clusters that would occur slightly above the breakpoints for the respective targeted certification.

Figure 6 disaggregates the credit totals by level of certification. As noted, the credit distributions were skewed to the right as might be expected due to the application of the breakpoints between categories. Interestingly, a significant number of projects were on the cusp between categories, with the modal response for each of the categories observed at the breakpoints (i.e. certified = 26, silver = 33, gold = 39 and platinum = 52). As such, it is likely that a significant number of projects could be subject to reclassification as the credit awards change with systematic reclassification.

After exploring the raw credit earnings by level of impact category per system the next stage of analysis involved the conversion of from the NC2-series to the NCv2009 system. Briefly, this was achieved by rescaling each of the 591 projects under the rules of the new standard and then determining whether the projects would retain their certification levels when compared to the new breakpoints delineating the different levels of certification. Table VIII provides a profile of the changes in credits by impact category between the two rating systems. As noted, the first three categories were

Statistic	Sustain. sites	Water eff.	Energy and atmos.	Materials and res.	Indoor env. quality	Innovation and design	All
Mean	6.79	3.03	6.51	5.36	8.59	3.83	34.12
SE	0.09	0.06	0.15	0.07	0.10	0.05	0.29
Median	7	3	6	6	8	4	33
Mode	6	4	5	6	8	5	26
SD	2.10	1.38	3.66	1.64	2.44	1.26	7.05
Sample var.	4.42	1.91	13.39	2.69	5.97	1.58	49.64
Kurtosis	0.0603	−0.8237	0.0320	0.6047	−0.3474	−0.4194	1.1163
Skewness	0.0141	−0.2888	0.6060	−0.3465	0.1045	−0.8095	1.0301
Range	11	5	17	11	13	4	35
Minimum	1	0	0	0	2	1	26
Maximum	12	5	17	11	15	5	61
Count	591	591	591	591	591	591	591
Conf. level (95%)	0.17	0.11	0.30	0.13	0.20	0.10	0.57

Table VII.
Descriptive statistics for credits by impact category for NC2-series

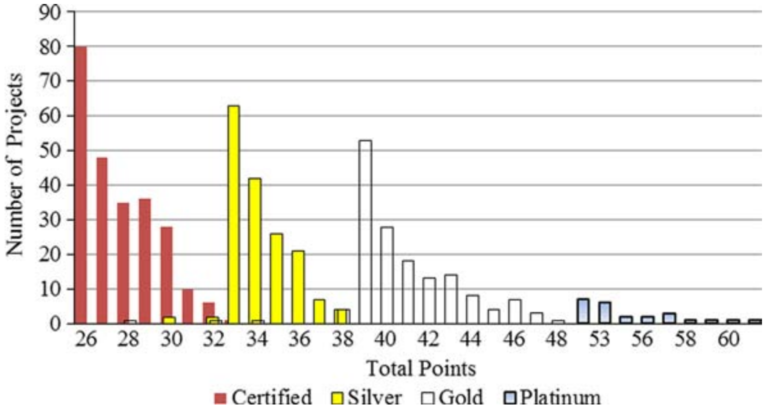

Figure 6. Distribution of credits/certification level vintage NV2-series

Impact category	Maximum credits NC2-series	Maximum credits NCv2009	Weights NC2-series (%)	Weights NCv2009 (%)	Change in weights Category changes (%)	Change in weights ± Cluster changes (%)
Sustainable sites	14	26	20.3	23.6	3.3	
Water efficiency	5	10	7.2	9.1	1.8	
Energy and atmosphere	17	35	24.6	31.8	7.2	12.4
Materials and resources	13	14	18.8	12.7	− 6.1	
Indoor environment quality	15	15	21.7	13.6	− 8.1	
Innovation and design	5	6	7.2	5.5	− 1.8	− 16.0
Regional priorities	0	4	0.0	3.6		
Total	69	110	100.0	100.0		

Table VIII. Conversion from NC2-series to NCv2009 vintage

effectively weighted upward and became relatively more important, while the latter three categories were weighted downward. The cumulative changes among the categories grouped into clusters of those that increased and those that decreased is fairly pronounced. Ignoring the new regional priority impact category, the three categories that increased in weighting gained 12.4 per cent while the three categories that declined lost 16 per cent. The net 3.6 per cent differences were attributable to the addition of four credits for the regional priority category.

Table IX presents the categorical multipliers used to convert the individual project credit scores using a modified Lagrangian multiplier process. The Lagrangian construct enables a consistent process that varies with context and situation. This approach enables a stochastic reclassification adjustment measure. The multipliers are calculated by comparing the NC2-series credits to the NCv2009 measures (i.e. SS $26/14 = 1.86$). Since the regional priorities were not included in the NC2-series, they were excluded from this phase of the analysis.

Once the impact category multipliers were calculated, the NC2-series credits for the 591 projects were adjusted to NCv2009 using the following equation:

$$\mathrm{NCv2009}_{\mathrm{IC1-6}} = \sum(\beta_1\delta_1 + \beta_2\delta_2 + \beta_3\delta_3 + \beta_4\delta_4 + \beta_5\delta_5 + \beta_6\delta_6)$$

Table IX.
Categorical multipliers

Impact category	Maximum credits NC2-series	NCv2009	Multiplier δ
Sustainable sites	14	26	1.86
Water efficiency	5	10	2.00
Energy and atmosphere	17	35	2.06
Materials and resources	13	14	1.08
Indoor environment quality	15	15	1.00
Innovation and design	5	6	1.20
Regional priorities	0	4	
Total	69	110	

where:

$IC_{1\text{-}6}$ = six impact categories common to both vintages.

n = 591 projects.

$\beta_{1\text{-}6}$ = NC2-series ratings by category 1-6.

$\delta_{1\text{-}6}$ = NCv2009/NC2-series impact category multipliers (Lagrangian form).

Adjustment for regional priorities

Once the projects were rescaled to the NCv2009 equivalencies for the six common impact categories, the credit scores were adjusted for the regional priority impact category. As suggested by the label, these "regional priorities" were established by the USGBC regional councils and chapters to incentivize developers to address attributes that were relatively for the region in which a project was located. Table X identifies the individual attributes for which a maximum of four regional priority credits (RPCs) could be earned.

Since there were no base credits for the regional category in the NC2-series addition of this new impact effect required an alternative approach from the rescaling that was applied to the other six categories. Figure 7 shows the adjustment process that was applied to incorporate RPC in the rescaling of the NC2-series credit scores. This involved several steps. First, the projects were assigned to the appropriate region using addresses and zip codes. Second, the eligible attributes for the respective regions were flagged. Third, the attribute credits awarded to a project under the NC2-series were analysed to determine if the project had addressed the eligible credits.

The final adjustment to the RPC bonus was to cap the individual categories to ensure that the maximum four credit bonus was not exceeded. Thus, RPC earned (RPC_{earn}) was calculated by:

$$(RPC_{earn}) = \sum SS^*_v w_{ss} + \sum WE^*_v w_{we} + \sum EA^*_v w_{ea} + \sum MR^*_v w_{mr} + \sum IEQ^*_v w_{ieq}$$

where:

w_{ss} = vector of eligible sustainable site RPCs/regional domicile.

w_{we} = vector of eligible water efficiency RPCs/regional domicile.

w_{ea} = vector of eligible energy and atmosphere RPCs/regional domicile.

Impact category	Attributes eligible for regional impact credits	Codes
Sustainable sites (SS)	Site selection	SS1
	Urban redevelopment	SS2
	Brownfield redevelopment	SS3
	Alt. transportation: public	SS4.1
	Alt. transportation: bicycle storage and changing rooms	SS4.2
	Alt. transportation: low-emitting and fuel efficient vehicles	SS4.3
	Alt. transportation: parking capacity	SS4.4
	Site development: protect or restore habitat	SS5.1
	Site development: maximize open space	SS5.2
	Storm water design: quality control	SS6.1
	Storm water design: quality control	SS6.2
	Heat island effect: non-roof	SS7.1
	Heat island effect: roof	SS7.2
	Light pollution reduction	SS8
Water efficiency (WE)	Water efficient landscaping	WE1.1
	Water efficient landscaping: no water	WE1.2
	Innovative water technologies	WE2
	Water use reduction	WE3
Energy and atmosphere (E&A)	Optimize energy performance	WA1
	On-site renewable energy	EA2
Materials and resources (M&R)	Building reuse: exteriors	MR1.1
	Construction waste management	MR2
	Materials reuses	MR3
	Regional materials	MR5
	Rapidly renewable materials	MR6
	Certified wood	MR7
Indoor environment quality (IEQ)	Increased ventilation	IEQ2
	Controllability of systems	IEQ6.1
	Thermal comfort	IEQ7.1
	Daylight and views	IEQ8.1

Table X.
Attributes eligible for RPC/impact category

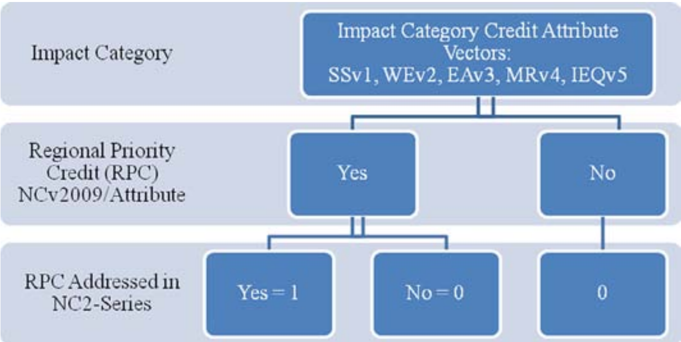

Figure 7.
Adjustment for RPC

w_{mr} = vector of eligible materials and resources RPCs/regional domicile.

w_{ieq} = vector of eligible IEQ RPCs/regional domicile.

Applying the constraint (i.e. maximum credit adjustment = 4), the RPC_{adj} for individual projects was:

$$RPC_{adj} = Max(RPC_{earn} \text{ or } RPC_{max} = 4)$$

Table XI presents the descriptive statistics for the 591 projects certified under the NC2-series after the credits were converted to the NCv2009 vintage series. As noted, the average score increased to 53.6 credits compared to 34.1 under the NC2-series vintage system (Table VIII). The most significant difference was in the regional priority impact category which had an average of 2.5 across all certification levels.

Table XII shows additional insights into market behaviour related to regional priorities, In general, projects that were on the margin in terms of certification and fell into the "unclassified category" when rescaled from NC2-series to NCv2009 paid less attention to regional issues than did projects that were in the higher categories. This is especially true with respect to platinum level projects of which 92 per cent hit the maximum on regional priorities.

Figure 8 provides insights into the distribution of projects in terms of credits after conversion to the NCv2009 series. The projects remained positively skewed, but exhibited less concentration around breakpoints than under the earlier LEED NC2-series. The negative skew of the "unclassified" projects that fell beneath the minimum threshold is also revealing, suggesting how the marginal projects that were on the cusp between two levels were downgraded as a result of the conversion.

Results of reclassification: 2005 LEED to 2009 ratings

Table XIII presents the results of the reclassification of the 591 projects that were certified under the NC2-Series projects and converted to the NCv2009 measures. Panel A presents

Statistic	Sustain. sites	Water eff.	Energy and atmos.	Materials and res.	Indoor env. quality	Innovation and design	Regional priorities	All re-scaled
Mean	12.60	6.07	13.40	5.77	8.59	4.60	2.53	53.56
SE	0.16	0.11	0.31	0.07	0.10	0.06	0.05	0.50
Median	13.0	6.0	12.4	6.5	8.0	4.8	3.0	51.5
Mode	11.1	8.0	10.3	6.5	8.0	6.0	2.0	40.8
SD	3.90	2.76	7.54	1.77	2.44	1.51	1.18	12.16
Sample var.	15.23	7.64	56.83	3.12	5.97	2.27	1.39	147.91
Kurtosis	0.0603	−0.8237	0.0272	0.6047	−0.3474	−0.4194	−0.8064	1.1760
Skewness	0.0141	−0.2888	0.6054	−0.3465	0.1045	−0.8095	−0.3497	1.0401
Range	20.4	10.0	35.0	11.8	13.0	4.8	4.0	65.0
Minimum	1.9	0.0	0.0	0.0	2.0	1.2	0.0	34.8
Maximum	22.3	10.0	35.0	11.8	15.0	6.0	4.0	99.8
Count	591	591	591	591	591	591	591	591
Conf. level (95%)	0.32	0.22	0.61	0.14	0.20	0.12	0.10	0.98

Table XI.
Descriptive statistics for NC2-series credits to NCv2009 vintage

Credits	Unclassified	Certified	Silver	Gold	Platinum	Total
Panel A: number of projects by RPC by certification						
0	7	17	6	1		31
1	21	33	19	17		90
2	11	72	47	29	1	160
3	4	58	45	48	1	156
4	1	31	43	56	23	154
Total	44	211	160	151	25	591
Panel B: share of projects by RPC by certification						
0	16%	8%	4%	1%		5%
1	48%	16%	12%	11%		15%
2	25%	34%	29%	19%	4%	27%
3	9%	27%	28%	32%	4%	26%
4	2%	15%	27%	37%	92%	26%
Total	100%	100%	100%	100%	100%	100%

Table XII.
RPC by certification level

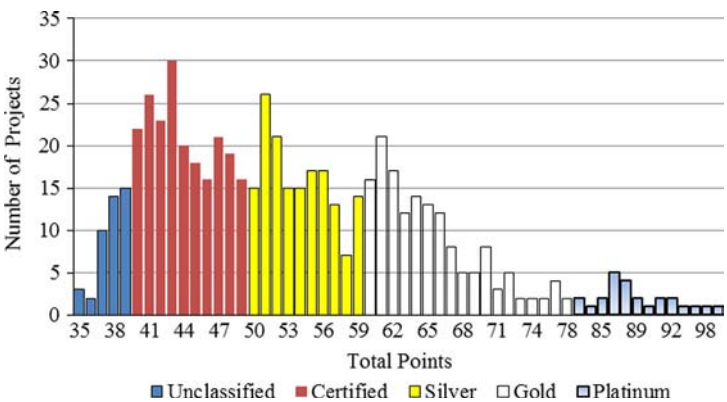

Figure 8.
Credit distribution by certification level for NCv2009 vintage conversion

NC2-series certification	NCv2009 certification Unclassified	Certified	Silver	Gold	Platinum	Total
Panel A: number of projects by certification level NC2-series vs NCv2009						
Certified	44	*187*	15			246
Silver		23	*131*	12		166
Gold		1	14	*139*	1	155
Platinum					*24*	24
Total	44	211	160	151	25	591
Panel B: share of projects by certification level NC2-series vs NCv2009						
Certified (%)	18	*76*	6	0		100
Silver (%)		14	*79*	7		100
Gold (%)		1	9	*89*	1	100
Platinum (%)					*100*	100
Total (%)	7	36	27	26	4	100

Table XIII.
Comparison of certification levels under NC2-series and NCv2009

the number of projects that fell into each of the respective categories for the two classification series. The bold diagonal indicates the number of projects that remained in the same category. The numbers that are to the left of the bold diagonal indicates projects that were downgraded by the conversion to NCv2009. On the other hand the numbers to the right were upgraded to a higher category. Panel B expresses the reclassification in percentage turns with the same bold diagonal to indicate the share that remained in the same categories. Of the 591 projects there were some significant changes in classification with 44 (7 per cent) of the "Certified" projects falling beneath the minimum breakpoint for the Certified Level and dropping into the "Unclassified" or category. On the other hand 24 per cent of the projects earning the "Certified" level under the NC2-Series changed after the conversion, with 18 per cent declining and 6 per cent increasing in certification levels. There were also significant changes in the Silver (21 per cent) and Gold categories (11 per cent), while the Platinum category was unchanged.

In addition to the aggregate levels of change in classifications when converting NC2-series classifications to NCv2009, it is useful to explore the absolute number of projects affected as well as the direction of the changes. Table XIV presents the number and share of projects that decreased or increased in classification levels as a result of the conversion to NCv2009 system. As noted, 44 “certified” projects declined in ratings while 15 projects moved up to the silver category. Similarly, 23 “silver” projects fell to the lowest (i.e. certified) classification, while 12 increased to gold. Of the original gold-certified projects, 14 slipped to Silver and one slipped to certified. The only class not affected by the reclassification was the platinum, which is due in part to the fact that projects in the highest classification already had most of the credits and were thus unaffected by shifts in weights or scores across categories. At an overall level, a significant number of projects were reclassified either up or down with 18 per cent projects (i.e. 108 of 591) either increasing or decreasing in certification levels.

Conclusion

In this paper we explored the durability of the “sustainable” value proposition by exploring the changes in classification of NC2-series vintage LEED buildings if they were subject to the new NCv2009 vintage rating system. As noted, the results are both dramatic and more significant than expected with over 18 per cent of the projects being reclassified. These results are consistent with the hypothesized behavioural response that developers would seek to minimize marginal costs by operating above the breakpoints in obtain the credits needed to achieve certain targeted levels of certification. While this strategy may have seemed a prudent risk management approach during the

Table XIV. Direction and overall level of reclassification

	Projects reclassified in NC2-series to NCv2009 conversion						
	Number of projects			Share of projects			
NC2-series certification	Decreased	Increased	Total	Decreased (%)	Increased (%)	Total (%)	Overall (%)
Certified	44	15	59	18	6	24	10
Silver	23	12	35	14	7	21	6
Gold	14	0	14	8	1	9	2
Platinum	0	0	0	0	0	0	0
Total	80	28	108	14	5	18	18

early adoption stages of the diffusion of innovation process, in some cases it may have backfired in terms of creating an unstable value proposition. Due to the lack of degrees of freedom, when the NC rating system changed in terms of impact category weights and with the introduction of regional priorities, the net change in credits had a significantly negative impact on classification levels.

Assuming the published research pointing to price premiums for LEED-certified buildings has been accurate, the results of this analysis suggest that such premiums may not be durable and may be subject to downward pressure. Indeed, in some cases the market may apply a discount to such projects to reflect the functional obsolescence associated with having a building that adheres to obsolete standards. For this to occur there must be sufficient transparency to overcome the complexity embedded in the certification process as it evolves over time. If this occurs, it would be inconsistent with the long-term parity between public and private sector goals built into the definition of sustainable real estate solutions. Whether the market will pick up on these differences and reflect them in future pricing will be the subject of future research. In some respects the complexity of the LEED rating system in general and changes that have been phased in over time may insulate owners from adverse pricing impacts as the standard of what constitutes a "sustainable building" continue to evolve. However, to the extent that the changes are valid and result in more efficient and sustainable buildings, then at some point the market will consider the "vintage" under which certification levels have been awarded pricing differentials. In the meantime, the market will have to figure out how to deal with the lack of transparency associated with certification system dynamics and reconcile the lack of a stable system compared to the long-term nature of real estate assets and sustainability objectives.

In reviewing the implications of this research, it should be noted that LEED 2012 is out for the third round of public comments and was scheduled to be introduced in Fall 2012. Based on public feedback, the date has been pushed back into 2013 and the vintage has been rebranded as LEED 4.0. The main differences between 2009 and LEED 4.0 are further changes to "impact categories" or credits scores that underlie the classification system. While the US EPA's TRACI impact categories were adopted for 2009, in preparing the new system, a new set of impact categories and credits is being developed by USGBC (2012). The new impact categories include: reduction in the contribution to global climate change; enhancement of individual human health, well-being, and vitality; protection of and restoration of water resources; protection, enhancement, and restoration of biodiversity and ecosystem services; promotion of sustainable and regenerative material resource cycles; creation of a greener economy; and enhancement of community: social equity, environmental justice, and quality of life. While the final version of the new vintage of NC-certification has been pushed back, it is clear that the complexity associated with LEED NC-certification will continue to increase. If history is any indicator of the future, the introduction of a new vintage of NC-certification will introduce more uncertainty and make it even more difficult for the market to accurately establish price premiums for various levels of LEED certification. This will be increasingly important for market-based investors where a significant part of any price premium depends on the exit value or terminal value at the end of the holding period. This concern suggests is time to step back and look at the potential "unintended consequences" of certification system dynamics that make it difficult to formulate durable investment strategies and pricing for LEED NC-certified investments. This is particularly true for institutional investors pursuing socially responsible investment in a fiduciary setting.

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Who will close the energy efficiency gap? A quantitative study of what characterizes ambitious housing firms in Sweden

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Abstract

This paper reports the results from a study that attempts to identify factors that characterize housing firms with particularly ambitious approaches to energy efficiency in connection to renovation. The aim of the study was to identify factors that correlate with ambitious firms and the market they operate in. The study builds on previous results that identified four ideal types among Swedish housing firms, ranging from not ambitious to very ambitious with regards to energy efficiency. Based on the ideal types, this paper uses three levels of ambition and focuses on the more ambitious levels to see if there are factors that co-vary with an ambitious approach.

Six hypotheses were formulated; ambitious firms were believed to be municipal, to be operating in markets with high and/or volatile energy prices, to be operating in strong markets, to have building portfolios in need of renovation, to be large and to have an expert employee who champions energy efficiency issues.

Using web survey results from housing firms, an ordered probit model was used to test if level of ambition as the independent variable and a number of firm and market specific factors as dependent variables The results indicate support for some of the hypotheses; the probability of being ambitious increases if firms are municipally owned, have a building portfolio in need of renovation and have an employee who champions the energy efficiency issues. There were no indications that high/volatile energy prices, strong markets or firm size influence the probability of being more ambitious.

Keywords: energy efficiciency, housing, sustainable renovation, incentives, drivers

1 Introduction

Following the past decades' climate debate, the potential to improve energy performance in the building sector has been proposed as a cost-efficient way to mitigate climate impact. The technical potential to reduce the 40 % share of total energy consumption and the third of greenhouse gas emissions accounted for by the EU building sector is large, and ambitious goals to reduce energy consumption have been adopted.

Parallel to this, academia has dedicated great interest in the so called energy efficiency gap, defined as the difference between 'optimal' and actual energy efficiency (see for example Jaffe & Stavins, 1994; van Soeste & Bulte, 2001; Allcott & Greenstone, 2012). It has been seen as a paradoxical that actors in the real estate market neglect energy efficiency investments in spite of their seeming profitability. The energy efficiency gap suggests that classic economic theory about profit maximizing firms fails. To explain the gap, various barriers have been identified and quantified, and alternative explanation models have been proposed, for example introducing behavioral economics models (e.g. Allcott 2011; Allcott & Mullainathan, 2010). Policy measures to remedy market failures have also been proposed. However, in order to successfully moderate or eliminate market barriers, a deeper understanding of actor behavior in connection to investments in energy efficiency is necessary (Allcott & Greenstone, 2012).

A study of Swedish housing firms and their views on energy efficiency in connection to renovation of 1960's and 70's multi-family buildings exposed variation in attitudes to energy efficiency among the firms, anything from a business-as-usual attitude to very ambitious goals to reduce energy use in the building portfolio (Högberg et al, 2009). Contrary to firms who appear to neglect profitable energy efficiency measures, the more ambitious firms carry out investments whose profitability can be questioned (Byman & Jernelius, 2013; Högberg & Lind, 2011). Given this spread, it is important to establish what factors are correlated to a more ambitious approach; different barriers will likely have an unequal(ly strong) impact on different firms, depending on what level of ambition they have chosen.

The aim of this study is to identify factors that characterize ambitious housing firms and the market they operate in. Ambitious firms are the kind of examples that have been sought after in the debate to help reduce the energy efficiency gap, e.g. considering theories about diffusion of innovation (Rogers, 1962). The indirect aim of this paper is therefore to improve conditions to design better policy tools.

A number of hypotheses have been formulated based on previous studies and knowledge about the Swedish real estate market. It is predicted that an ambitious housing firm

a) is municipal,
b) is operating in a market characterized by high and/or volatile energy prices,
c) is operating in a strong market where demand for housing is high,
d) has a building portfolio in need of renovation
e) is large, and
f) has an (expert) employee who champions the energy efficiency issue.

The study primarily builds on web survey data and focuses on private and municipally owned (public) housing firms that own multi-family buildings constructed in the 1960's and 70's, a period in Swedish building history known as the Million Homes Program.

The structure of the paper is as follows. Section 2 serves as a background to the conditions in the Swedish housing market. The analytical framework is described in section 3, section 4 presents the method and data and results are presented in section 5. Results are discussed in section 6 before drawing conclusions and discussing implications.

2 The Swedish housing market and energy efficiency possibilities

There are approximately 4.5 million dwellings in the Swedish housing market, out of which 2.5 million dwellings are multi-family apartments. Two thirds of the 2.5 million are rental apartments (Statistics Sweden, 2013).

The multi-family stock and its characteristics

A large share, 25 % of the Swedish housing stock was constructed in the 1960's and 70's. The period between 1961 and 1975 is unprecedented in Swedish building history in terms of growth. The period has become known as the "Record Years", when more than a third of today's multi-family dwellings were built. Although over one million dwellings of different variety were constructed between 1965 and 1974, the term "Million Homes Program" (MHP) has colloquially been used to describe the large-scale housing areas from this period. The Million Homes Program was initiated to combat housing shortage and poor housing quality, and an industrial approach including prefabricated building elements made the project possible. The many contributing developers, an openness to experimenting with building techniques, the then building regulations and time pressure to finish within the ten years have all contributed to create a variety in quality between the buildings, e.g. in terms of standard and energy performance.

According to previous estimations, 850,000 multi-family dwellings constructed in 1961-75 remain today. Out of these, 390,000 (46 %) are owned by municipal housing firms, 222,000 (26 %) are owned by private firms and individual owners and 242,000 (28 %) are owner-occupied housing co-operatives (Boverket, 2003).

Technical status, costs and profitability

By estimate, approximately 300,000 publicly owned multi-family dwellings and a total of 650,000 multi-family dwellings in buildings from the MHP are in need of renovation (Industrifakta, 2008, see table 1).

Table 1 Estimation of the multi-dwelling building stock constructed 1961-75, *by owner category in 2002* (Industrifakta, 2008).

The Million Homes Program	Number of dwellings	In need of renovation
Municipal firms	390,000	300,000*
Private owners	220,000	
Housing co-operatives	240,000	
Total	**850,000**	**650,000**

*SABO (2009)

Most of the buildings have not been renovated since they were built and are now in need of new piping, electricity wiring and other installations. Many of the buildings are also in need of measures to improve the building envelope and energy consumption is generally higher than in other parts of the Swedish building stock (Industrifakta, 2008). According to industry assessments, investments needed to raise the buildings above the minimum technical acceptance level (correcting technical deficiencies that cause unacceptable to living conditions, that imply large costs to the firm or puts the building survival at risk), amount to around 2,000 SEK per square meter. To renovate selected parts (e.g. piping and ventilation) to improve technical and indoor standard would cost around 6,000 SEK per square meter and to completely renovate up to new construction standard, including energy efficiency improvements, would cost around 12,000 SEK per square meter (SABO 2009). Costs for energy efficiency improvements in this type of buildings vary greatly depending on the type of measure and the conditions of the building. In general, extensive measures that improve the building envelope and (potentially) greatly improve energy performance are the most costly. Measures that improve the performance of installations, such as replacing the ventilation system, vary from very costly (in particular if the building needs technical adaptation to fit the new system) to negligible. The least costly measures are usually connected to energy savings, such as motion detector lighting (VVS-företagen, 2009).

Regulatory framework

Directive 2010/31/EU on the Energy Performance of Buildings (EPBD) and Directive 2012/27/EU on energy efficiency put pressure on Swedish energy performance in buildings. Sweden has previously adopted a general energy efficiency goal to improve energy efficiency by 20 %between 2008 and 2020 and in addition to this goal there is a guiding goal of 9 % reduction in energy consumption by 2016 (compared to the annual average 2001-2005). The Swedish national building code is an extension of the EU regulation and requires energy performance in existing buildings to adhere to new construction standard if renovations affect a substantial part of the building (BFS 2014:3 BBR21). Existing policy measures to incentivize improvements in building energy performance are mostly informational; the building owner generally bears additional costs due to regulatory demands (Byman & Jernelius, 2013). The Swedish housing market is rent regulated and rent levels essentially follow inflation (Lind 2003). Rents are generally only increased after negotiations between (representatives for) landlord and tenants, and only measures which increase the standard of the dwelling qualify for rent increases. Energy efficiency measures mostly impact the exterior parts of the building and thus rarely qualify for rent increases. There are a few possible exceptions that may influence the indoor environment, mechanical ventilation with heat recovery being one example. Furthermore, in 2011 the Swedish parliament passed the new Public Municipal Housing Companies Act (2010:879) which specifies that publicly owned housing firms must act in a "business-like manner" to ensure fair competition among all housing firms. Other legal considerations firms need to consider include adaptation of buildings to current accessibility requirements and preservation of architectural and cultural/historical values (BFS 2014:3 BBR21).

Implications for the study

The MHP makes for an interesting case study since the renovations constitute a great challenge but also potentially a "golden opportunity" for housing firms to upgrade their building portfolio for a substantial period of time ahead (OECD, 2013). This presupposes that the housing firm has the necessary resources to do so and depends on whether the firm's investment behavior is proactive or reactive. Regardless, within the sector, there is much need for renovation in these buildings (SABO, 2009; Industrifakta, 2008), and this situation forces many firms to (re)act. The regulatory framework will put limits to what (some of) the housing firms want to and are able to do to improve energy efficiency, and focus in this study will be on what characterizes firms whose ambition is to substantially improve energy efficiency.

3 Analytical framework

This section outlines some key features of a stylized profit-maximizing housing firm and its actions in connection to renovations and energy efficiency improvements. In the next two sections, the hypotheses are developed about why a Swedish housing firm with buildings from the MHP in need of renovation could deviate from the stylized firm.

3.1 The profit-maximizing firm and general drivers of energy efficiency improvements

Energy consumption is endogenously determined as it is an input factor used to produce the service 'housing' (Davis, 2008). A profit-maximizing housing firm who owns and manages buildings at the end of their technical life cycle will consider a number of factors when planning upcoming renovation and energy efficiency activities; this stylized firm will maximize profits given the regulatory framework, the technical status of the buildings, tenant demand, market situation and the time horizon of the investment as well as of its ownership.

The level of ambition of the firm can be based on three types of factors. Energy efficiency is (i) a policy matter, determined by publicly provided incentives. The absolute minimum level of "ambition" for a firm is to live up to current building code, a piece of legislation resulting from national as well as international political processes. Failure to meet these requirements may result in sanctions which the firm will seek to avoid. The same political processes may also yield aims and goals related to energy efficiency – general goals for which there may be no government possibility (nor will) to sanction non-compliance. Like any Swedish housing firm, the stylized firm will need to meet minimum requirements. The political landscape and market structure as well as the firm's characteristics and abilities will determine how much above this minimum level the firm will aim for.

Above what is given by the regulatory framework, investments in energy efficiency are (ii) an economic matter, determined by price signals in the market in which the firm operates. Energy costs make up a substantial part of operating costs and energy consuming installations, some more than other, need maintenance. A profit-maximizing firm will carry out investments with a positive net present value (NPV), and given limited resources (such as capital funds and number of employees), only the investments which generate the highest NPV in relation to other competing investments.

Energy efficiency may finally be (iii) an ethical matter contributing to the firms' Corporate Social Responsibility (CSR) efforts. In addition to the two drivers above, the negative environmental impact of building energy consumption may push the firm to, for reasons of altruism or image-concerns, choose an even more ambitious strategy than what is strictly dictated by legislative requirements and economic predictions (Bénabou & Tirole, 2006; 2010). This may for example depend on circumstances like owner preferences, a dedicated champion of energy efficiency questions or engaged tenants who value environmental issues highly, issues that will be discussed more in the next section.

The impact of points (ii) and (iii) on firm energy ambition may be large or small in relation to building code requirements. If the firm faces high energy prices, investments in energy efficiency improvements should be more profitable and thus type (ii) factors should drive ambition to a higher level as a straight-forward response to price signals in the market. Regarding type (iii) factors, image-concerns may drive a firm to ambitious energy efficiency work to avoid stigma or seek honor (Bénabou & Tirole, 2010). Negligible energy efficiency efforts driven by image-concerns may however sort under "green-wash", a type of free-rider behavior that casts doubt on the virtuosity of other truly ambitious firm and risk crowding out their efforts (Zaman et al. 2010; Bénabou & Tirole, 2010). It can also be noted that the impact on ambition of both type (ii) and (iii) factors may be zero.

3.2 The notion of "ambitious firm"

To arrive at a definition of an ambitious firm, I start by proposing four ideal types of housing firms active on the Swedish housing market. I then focus only on the firms whose ambition for energy efficiency is in fact higher than merely fulfilling building code and investing in measures with a short payback period. This kind of forerunners may be necessary to set an example and potentially lead the diffusion of innovation. However, this would require investments in energy efficiency measures that go beyond what many firms consider profitable, and that could crowd out the firm's potentially more profitable investment options. Their behavior would thus contradict the expectations of how a profit maximizing firm behaves and is therefore of interest for policy design.

Högberg *et al.* (2009) categorized and divided housing firms into a) Short-term Profit Maximizing Companies (SPMC), b) firms who do "a little extra" (Little Extra Companies, LEC) and two types firms who are ambitious about improving energy performance. High energy ambitions can be driven either by c) dedicated owners (Policy Led Ambitious Company, PLAC) or by d) dedicated staff (Administration Led Ambitious Company, ALAC).

SMPC firms typically focus on saving (i.e. not using) energy, but is more often following a business-as-usual approach. Firms may be SPMCs out of necessity (e.g. firms whose access to investment capital is limited or who operate in a weak market), out of ignorance (e.g. small firms with no specific energy-related competence) or for strategic, economic reasons. There are examples of SPMC firms who are generally skeptical to energy efficiency investments and therefore only reluctantly make calculations, or make the calculations using unreasonably high discount rates or short payback times (Högberg *et al.*, 2009).

Firms that do a little extra (LEC), have an expressed interest in carrying out measures that will benefit the environment and reduce energy use. What distinguishes the LECs from the SPMCs is the more systematical process by which the firm is perceived to be working with energy efficiency improvements. The systematic approach does not, however, mean that the LEC firm will carry out any saving or efficiency measure; a sound economic assessment is the rationale for investment decisions. This is to say that no naïve or overly optimistic calculations regarding the energy savings, risk assessments (and discount rate), future energy prices and service life are made. Potential synergy effects from coordinating measures, taking into account financing and available resources, can also be included to optimize the life-cycle economics of the building (ibid).

The two types of ambitious firms – merged into one Ambitious Company category (AC) in Högberg & Lind (2011) – have declared ambitious goals for energy savings and clearly proclaim how they are working with their building portfolio to reach them. Although tenants are expected to contribute to achieving the goals, the firms independently take responsibility and aim to reduce energy use in their properties in a systematical and comprehensive way. AC firms are being backed up in this effort by their owners and in some cases have the owners' blessing to not let economic considerations dominate decision making, e.g. by allowing a significantly lower discount rate, by using the total project method (Abel et al, 2012) where profits from some energy-efficiency measures are used to subsidize unprofitable energy-efficiency measure, or by directly subsidizing energy efficiency projects.

Based on the description of the two latter ideal types, the following definition can be made.

An ambitious housing firm is one with a pronounced commitment to improving energy efficiency in its existing building portfolio. The firm is motivated to exceed building code energy performance and short-term economic gains by a) long-term economic drivers and/or by b) ethical drivers.

Following this definition, an ambitious firm is expected to comply with building code and invest in energy efficiency measures that have short-term economic pay-off. However, the ambition of interest is what goes beyond regulation and short-term profit. The commitment is not legally binding and the firm cannot be held legally accountable for not fulfilling their aims. The firms motivate their commitment economically by claiming to be a (very) long term investor which reduces and/or impedes future energy cost increases. Commitment is motivated ethically by taking environmental responsibility through reducing energy use.

Measuring actual investment outcome for different types of firms is beyond the scope of this study; it is nonetheless assumed that an ambitious firm will end up doing more to improve energy efficiency than a not ambitious firm.

3.3 The hypotheses

To gain increased knowledge about ambitious firms and the conditions they face, the aim is to identify factors that co-vary with the level of ambition. Firstly, it is of interest to examine factors that have been identified as drivers for energy efficiency in previous research. Secondly, it is interesting to examine factors which may be suited to target with policy measures to stimulate ambition and increase energy efficiency investment uptake.

Analogous to the types of factors listed in figure 1, equation 1 illustrates a simple model.

$$P(amb) = a + b1*policyreq + b2*economic + b3*ethical + e \qquad (1)$$

The probability that a firm is *more ambitious* (than simply complying with code) is related to the level of the building code (policy requirement), on the profitability (economic factors) and on the extent of voluntary responsibility taken (ethical factors). Note that causality is not clear, the general level of ambition may well influence policy requirements as well as the economics of this type of investment. To start examining how various factors may influence the level of ambition for energy efficiency, we now turn to previous research.

Policy requirements

The Swedish building code is relatively strict and adapted to three local climate zones and in order to equalize the impact across the country the required energy performance is stricter where the climate is milder (BFS 2014:3 BBR21). In theory, one could predict that depending on the level of this factor, it would have either a positive or a negative (relative) impact on level of ambition. If the building code requires only a low energy performance, firms may find easy measures to improve energy performance above this level, so called low-hanging fruits. If there are general, social ambitions to reduce energy use, the firms might also anticipate stricter legislation in the future, which also could be a driver to improve energy efficiency. If the building code is strict and requires a high energy performance, the consequence may be that only few, if any, energy efficiency measures beyond this are profitable. Moreover, if there are no means or political will to sanction non-compliance, the incentives for housing firms to perform according to or above code are weak, and weaker the stricter the code, the more expensive the investments and and/or the harder the energy savings.

In practice, policy makers are cautious about implementing stricter building codes to avoid adverse effects from conflicting requirements and unfair distribution of costs (Gillingham & Palmer, 2014). Few ex-post evaluations of the impact of building codes exist, but a limited number of studies point to a small but significant impact (Jacobsen & Kotchen, 2013; Aroonruengsawat *et al*., 2012) despite that energy standards are considered a blunt policy instrument. These evaluations refer to new construction, which means that the impact on energy performance in connection to existing building renovation, should be smaller than the stated estimates.

Economic factors

The attractiveness of energy efficiency investments may vary from one housing firm to another; the combination of input factors (energy being one) used in each production technology and the price of these, the current and desired status of the existing physical capital, firm characteristics and market conditions will matter. More specifically, the expected profitability of an energy efficiency measure depends on

- initial investment cost,
- changes in net operating income (NOI),
- discount rate,
- calculation period (life length of the investment) and
- (to some extent) possible financial leverage.

Each of the components in turn depends on various factors. The initial investment cost for implementing a certain EE measure may have associated transaction costs and for example be higher for a firm which needs to educate its staff to be able to install it, or lower if the EE investment is one at the margin when the firm is already carrying out some other measure. The expected increase in NOI may be higher for a firm who has high energy consumption now and/or who face a high energy price. On the other hand, the NOI increase may be lower for a firm which cannot expect any rent increases.

Allcott & Greenstone (2012) describe the decision rule for a profit maximizing firm, where the investment is carried out (or a more energy efficient good is chosen over a less energy efficient good) if the initial cost is lower than the discounted value of implicit importance of energy cost savings, private energy costs, utility from using the energy consuming good, the difference in energy intensity between the more and less energy efficient goods and the unobserved incremental opportunity cost or utility cost from the more energy efficient good. Allcott & Greenstone (2012) also point out that the latter cost is often disregarded and always hard to measure in engineering studies and other estimations of investment profitability. The opportunity/utility cost may be positive to the firm, meaning it's less attractive to carry out the investment, or in the case of an unobserved benefit, the opportunity/utility cost may be negative, making the energy efficiency investment attractive to the firm. Cooremans (2012) describes how this may be part of a strategic investment logic; the extent to which costs and risks may be reduced and revenues increased, may be more important than the overall profitability of an investment.

Past energy costs, on the other hand, are observable, as is the status of the physical capital and the renovation needs. The levels and fluctuations of energy prices will influence the profitability assessment. General needs for renovation may open up for possibilities to concurrently undertake energy efficiency measures, which possibly reduces the marginal upfront cost and/or the opportunity cost of the measures. On the other hand, additional energy efficiency measures may also increment the total upfront cost for renovations, which may impede such investments even at a positive net present value of future energy cost savings (Fleiter *et al.*, 2012; Jakob, 2006).

Another transaction cost involved that increases the opportunity cost is that of investigating new solutions; costs for searching for and implementing new technology which may be augmented in a small firm where (human and financial) resources may be limited. In a larger firm, internal specialization may allow dedication of resources to find and test solutions on a small scale (e.g. pilot projects) which if successful can be applied to a larger number of buildings, thereby making economies of scale in production possible (González-Benito & González-Benito, 2006).

Some factors may influence profitability on a micro level, for example depending on the characteristics of a specific building portfolio or the firm's financial credibility, whereas other factos may vary on more of a macro level, for example depending on local energy prices. "Macro" level factors that may influence the NOI could also include other aspects of the local economy and its housing market. In strong markets, the profitability of energy efficiency measures may be higher than in weak markets, for example due to lower search costs for contractors willing and able to carry out energy retrofits. One could argue that strong markets may inflate labor costs, thereby reducing profitability. This, however, can be countered by arguing that (among other things) the degree of competition among contractors is likely to be higher and in general, economies of scale should be easier to accomplish, thereby lowering the upfront cost. Furthermore, in strong markets the possibility to increase rents is most likely better.

Ethical factors

Individual firms may find various motivations for adopting high ambitions for energy efficiency – as part of pro-environmental work – even beyond what is strictly profit maximizing (Hahn *et al.*, 2010; Bénabou & Tirole, 2010). For public housing firms, this may be a reinforcement of local political factors; an environmentally active local parliament will most likely influence the decisions of the politically appointed board of the municipal housing firm. To the extent that the local parliamentary representation reflects local market demand, private firms may also respond to such a factor by acting more ambitious with regards to energy efficiency, either as a general response to the (local) market, or as an individual response by firms marketing themselves towards a certain market segment. In both of these cases, ethical motivation is at least coupled with a profit increasing (if not maximizing) idea. There may, however, be individuals within a firm who are able to influence the firm to become more ambitious because of their own conviction of its added value (Brief & Motowidlo, 1986; Malmqvist & Noring, 2009). Such energy champions may be able to push the firm in a more ambitious direction, especially if they are part of or close to top management. For dedicated management, for example, lowering energy consumption may be a way to maximize utility as well as to maximize profits (Nakamura et al. 2001). Dedicated managers will also facilitate resource availability and coordination (see e.g. Delmas & Toffel, 2004).

Based on this discussion, it is predicted that an ambitious real estate firm

a) is municipal,
b) is operating in a market characterized by high and/or volatile energy prices ,
c) is operating in a strong market ,
d) has a building portfolio in great need of renovation ,
e) is large , and
f) has an expert employee who champions the energy efficiency issue .

4 Method and data

In order to examine what factors co-vary with the firms' level of ambition, an econometric model is designed. The dependent variable is *level of ambition* and is described in more detail in section 4.2. The independent variables are based on available data related to factors discussed in section 3.3 and the model including the independent variables is described in section 4.3. The empirical section is opened by describing the data.

4.1 Data

A web based questionnaire was sent to Swedish housing firms in January and February of 2010. The questions were based on results from an interview study carried out in 2009, where 16 Swedish housing firms, 3 private and 11 municipal, were interviewed (Högberg *et al.*, 2009). The 16 firms viewed energy efficiency investments too differently to allow generalization for how housing firms think and act. However, the differences were not large enough to prohibit predictions about how a single firm could be expected to act; some firms were similar enough to allow grouping into categories, resulting in the four ideal types described in section 3.2 above.

The questions had been tested on a reference group consisting of people from the industry. The municipal firms received the questionnaire through the Swedish Association of Municipal Housing Companies' [SABO] own survey system. The private firms were addressed through an online survey tool (Surveymonkey 2010). The aim was to target the total population, whereby the survey was sent to all member firms of SABO (288 housing firms owned by municipalities), and to all private firms that could be found on industry web pages (a total of 60). The private firms who were not reached are assumed to be "too small", considering that they don´t market themselves, and are therefore not expected to affect the implications of the survey results. 87 public and 24 private firms responded, a total number of observations [n] of 111.

Categorization of respondents into ideal types was done based on stated goals, declared previous efforts and results. The survey questions included background information about the respondents, the firms and the characteristics and renovation status of and strategies for the building portfolios. There were also questions about the firms' goals for energy efficiency as well as whether and how they performed investment analysis. In addition to this, the firms were confronted with a number of affirmations about renovation, energy efficiency investments, the legal and policy frameworks, investment considerations and decisions.

Response rate and non-response

111 firms answered the survey, resulting in a response rate of 32 %. The responses of late responders (those who answered the survey after reminders had been sent out) have served as proxy for the non-responding, to test if their answers differ from the average of those who have answered. No systematic differences have been found among those late respondents compared to the sample as a whole. Some selection bias may result from the fact that only larger private firms were targeted. As previously mentioned, this is not believed to effect the implications of the results, but should be kept in mind.

The dataset has been complemented with additional information, mainly from the firms´ web sites. Geographical location and some local economic data have also been collected.

4.2 Dependent variable – level of ambition

To analyze what factors are related to how ambitious a housing firm is, we think of the variable *threeambtype* as a latent index which measures level of ambition regarding energy efficiency improvements. The variable has three outcomes, "Not ambitious", "Somewhat ambitious" and "Very ambitious", scored 1-3, and corresponding to the three ideal types SPMC, LEC and AC described above. The binominal variable *amb* was also created, which takes on 1 if the value of *ambtype* is 2 or 3 (LEC or AC).

Classification of housing firms – ideal types

Some of the questions were intended for classification according to ideal types but due to possible misinterpretation and partial drop-out, the classification questions were supplemented with information from the firms' websites and official documents to carry out the classification. The four ideal types were reduced to three ambition levels due to difficulties in identifying the main external or internal motivating force. In addition, too few respondents per ideal type would have inhibited some of the analysis. Table 2 shows how the respondents were classified in accordance to the most relevant ideal type. To learn more about how the assessment and delimitation for classification of housing firms was done, see appendix A.

Table 2 Summary of categorization for sample companies

	SPMC	LEC	AC	Total
Private	16 (67 %)	8 (33 %)	0	24 (100 %)
Public	19 (22 %)	52 (60 %)	16 (18 %)	87 (100 %)
Total	**35 (32 %)**	**60 (54 %)**	**16 (15 %)**	**111 (100 %)**

4.3 The model

Building on the arguments in section 3.3, the hypotheses are tested by including relevant variables in an econometric model.

Among political factors, the building code is essentially the same across Sweden. The climate zone is included to control for whether adaptation of code to regional weather conditions makes it varyingly difficult to comply. Some Swedish municipalities previously adopted stricter energy efficiency requirements for new construction. To the extent that this also influenced housing firms' ambitions for existing buildings, this could potentially matter in how ambitious housing firms become. Since there is no data available on which these municipalities are, it has not been possible to control for such influence in this study. Instead, a dummy variable for a Social Democrat (SDP) or Left Party ("left" rule) majority and one variable indicating the share held by the Green Party in the local parliament were included. It is assumed that these three parties will have more of prosocial influence on the outcome. As a measure of political stability, a dummy variable that indicated a change of the political majority (in either direction) between the elections of 2002 and 2006 was included. Finally, a dummy variable indicating if the housing firm is municipally owned is included, as the impact of any policy related variable is likely to be stronger for municipal firms.

The included economic factors that may influence the level of ambition may be divided into supply and demand side factors. On the supply side, the highest energy price (district heating) in the (then) past five-year period, and the difference between the highest and the lowest energy price in the same period were included to control for high energy prices and for volatile energy prices. There was also a self-reported variable indicating how the respondents view future energy prices, whether future energy prices will 1) follow inflation, 2) rise slightly more than inflation (2-4 % above) or 3) rise substantially more than inflation (>5 %)". To control for physical status and renovation needs of the firms' building portfolios, a variable was created that took on value 1 if the respondents reported that the MHP buildings had been renovated in the 1990's or 2000's (assuming less urgent needs now), took on 2 if the buildings had been renovated in the 1980's or 1970's, and took on value 3 if the buildings had only had running maintenance or not been renovated at all since they were built (assuming more urgent needs now). An interaction variable using renovation needs and the share of MHP buildings was also included, since the renovation burden should be aggravated if the housing firm has a large "renovation hump". The shares of MHP buildings to total were divided into a five-step scale, going from 1 for 0-20% to 5 for >80%. Another variable was created to try to control for the renovation needs using the affirmation "The upcoming renovations of the buildings from the 1960's and 70's constitute a great challenge (are a heavy question) to our firm". Affirmations were answered on a five-point Likert scale using the options *Fully agree*, *Mostly agree*, *Don´t know*, *Agree to some extent*, *Don´t agree at all*, where the options have been coded from 5 *Fully agree* to 1 *Don't agree at all*. The number of employees was included as a proxy for firm size.

On the demand side, one variable indicating if the housing firm is located in one of the three largest metropolitan areas was included. To indicate the economic conditions of the local real estate market (the municipality, for all real estate types), a five-step ranking based on five indicators (population, population growth, unemployment, mean income and degree of self-sufficiency among inhabitants) was included.

The influence of factors on the ethical level should partly be picked up by the policy related variables described above. In addition to these, a self-reported variable indicating if there is someone(s) within the firm who pushes the energy issue within the firm, interpreted as the presence of an energy champion. Table 3 shows the included variables, the possible outcomes and the expected sign of these variables.

Table 3 Independent variables derived from hypotheses

Type of factor	Variable	Outcomes	Expected sign
Political	Climate zone	1-3	?
	Left* majority in local parliament 2006	0/1	+
	Share of Green Party in local parliament 2006	0-1	+
	Change of political majority between 2002 and 2006	0/1	?
	Public	0/1	+
Economic/ supply	Highest energy price 2005-2010	0-	+
	Difference in energy price 2005-2010	0-	+
	Expected energy price	1-3	+
	Renovation needs**	1-3/5	?
	Share of MHP buildings (scale)	1-5	-
	Number of employees	1-	+
Economic/ demand	Market strength***	1-5	-
	Metropolitan area****	0/1	+
Ethical	Energy champion	1-5	+

*Social Democrat Party and/or Left Party

**Time since renovation, if ever, or answer to affirmation "The renovation of the 1960's and 70's buildings is a heavy question for our firm"

***Newsec classification, 1 indicated the best local real estate market conditions (thus the negative expected sign).

**** The three metropolitan areas include municipalities:
Stockholm Metropolitan Area (MA): Botkyrka, Danderyd, Ekerö, Haninge, Huddinge, Järfälla, Lidingö, Nacka, Nykvarn, Nynäshamn, Salem, Sigtuna, Sollentuna, Solna, Stockholm, Sundbyberg, Södertälje, Tyresö, Täby, Upplands-Bro, Upplands-Väsby, Vallentuna, Vaxholm, Värmdö and Österåker.
Göteborg MA: Ale, Alingsås, Göteborg, Härryda, Kungsbacka, Kungälv, Lerum, Mölndal, Partille, Stenungssund, Tjörn, Vårgårda and Öckerö.
Malmö MA: Burlöv, Kävlinge, Lomma, Lund, Malmö, Staffanstorp, Svedala, Trelleborg and Vellinge.

To test the hypotheses, I run an ordered probit model on the regressors that we have hypothesized will have an impact and other control variables. The ordered probit model is chosen since there is a natural ordering in the discrete outcome variable, even if the magnitude of the difference between the three steps is unknown and unobservable. A number of different factors were tested and the ones described below were included in the final model.

P(threeambtype) = a + b1*climatezone + b2*leftrule + b3*GPshare06 + b4*polchange0206 + b5*public + b6*maxeprice20052010 + b7*diff_eprice + b8*exp_eprice + b9*ren_needs + b10*shareMHP + b11*ren__MHP + b12*no_employed + b13*market + b14*metropolitan + b15* champion + e (1)

4.4 Descriptive statistics

Table 4 gives an overview of the data. As previously noted, approximately one third of the sample firms are classified as not ambitious SPMC, slightly more than half of the firms are the somewhat ambitious LEC firms and almost 15 % of the firms are very ambitious AC.

A majority of the sample are located in climate zone 3 (southern parts of Sweden) and less than 5 % are located in the coldest parts of climate zone 1. Almost 40 % of the firms are located in municipalities governed by SDP or the Left Party since the elections of 2006, and slightly over 40 % had a change in the political majority between the elections of 2002 and 2006. Approximately 5 % of the firms were located in municipalities where the change in majority in 2006 resulted in an SDP or Left Party local government. In the local parliaments of the municipalities of the sample firms, the Green Party was represented by on average 4.7 %, ranging from practically no representation to a share of almost 10 %. The majority of the sample firms, almost 80 % were public.

The maximum energy price over the period of 2005 and 2010 was on average 71.64 SEK, ranging from 47.7 to 84.63 SEK. This resulted in a difference between the highest energy price and the lowest energy price during the period of on average 11.65 SEK, with a low of 0 and a high of 45.92 SEK. A majority of the sample firms, about 60 %, believed that energy prices would rise slightly more (+2-4 %) than inflation, while slightly more than 20 % believed it would follow inflation and slightly less than 20% believed energy prices would rise substantially more (>5 %) than inflation.

The average number of employees in the sample firms is 58, ranging from 1 to 257. The average firm owns about 4,000 dwellings, ranging from 356 to 30,000. Approximately half of these buildings, around 2,000, were constructed during the Million Homes Program of the 1960’s and 1970’s, where as little as 5 % of the buildings owned or as much as all of them may be from this period. A majority of the firms agree fully or mostly to the statement that the upcoming renovations constitute a challenge. Approximately one quarter of the firms have renovated their MHP buildings in the 90’s or 00’s (and presumably have less urgent needs now), almost one fifth of the firms have done so in the 1970’s or 1980’s, and just above half of the firms have not renovated their MHP buildings or have only done running maintenance since they were built.

37 % of the firms fully agree that they have someone, an energy champion, who pushes the energy issue within the firm, another 23 % mostly agree to this, while 10 % don’t agree at all.

Table 4 Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
threeambtype1 (SPMC)	111	0.315	0.467	0	1
threeambtype2 (LEC)	111	0.541	0.501	0	1
threeambtype3 (AC)	111	0.144	0.353	0	1
climatezone1	111	0.045	0.208	0	1
climatezone2	111	0.126	0.333	0	1
climatezone3	111	0.829	0.378	0	1
leftrule	111	0.396	0.491	0	1
polchange0206	109	0.413	0.495	0	1
change_left	109	0.055	0.229	0	1
GPshare06	111	0.047	0.024	0.001	0.094
public	111	0.784	0.414	0	1
maxeprice20052010	99	71.639	7.683	47.7	84.63
diff_eprice	99	11.652	8.137	0	45.92
exp_eprice	104	1.942	0.636	1	3
exp_eprice1 (~inflation)	104	0.231	0.423	0	1
exp_eprice2 (+2-4%)	104	0.596	0.493	0	1
exp_eprice3 (>5%)	104	0.173	0.380	0	1
no_employed	111	58.108	58.417	1	257
no_dwellings	110	4,174.591	5,169.832	356	30,000
no_MHPdwellings	109	2,031.697	2,219.792	52	10,000
shareMHP	109	0.533	0.212	0.047	1
shareMHP_scale	111	3.216	1.065	1	5
ren_challenge	108	3.833	1.431	1	5
ren_needs (last renovated)	106	2.302	0.853	1	3
ren_needs1 (90's, 00's)	106	0.255	0.438	0	1
ren_needs2 (70's, 80's)	106	0.189	0.393	0	1
ren_needs3 (no/running only)	106	0.557	0.499	0	1
market	111	2.568	1.262	1	5
market1	111	0.306	0.463	0	1
market2	111	0.144	0.353	0	1
market3	111	0.261	0.441	0	1
market4	111	0.252	0.436	0	1
market5	111	0.036	0.187	0	1
metropolitan	111	0.324	0.470	0	1
champion	108	3.463	1.500	1	5
champion1	108	0.111	0.316	0	1
champion2	108	0.287	0.454	0	1
champion4	108	0.231	0.424	0	1
champion5	108	0.370	0.485	0	1

5 Results

The independent variables were included in the model in several steps. First, each type of factor (policy, economic, ethical) were included separately, to test how much could be explained by the model in each step. In the final step all of the variables were included together, before testing the marginal impact of the independent variables on the probability of becoming more ambitious, from not ambitious (1) to somewhat ambitious (2) as well as from somewhat ambitious to very ambitious (3).

5.1 Regression output

Table 5 shows the parameter estimates for all of the regressions. The pseudo R^2 indicates a clear improvement when adding all of the variables, compared to any of the regressions using only separate types of factors. Asterisks mark statistically significant parameter estimates in the table.

Table 5 Parameter estimates, standard errors in parenthesis

threeambtype	Policy	Economic, supply	Economic, demand	Economic, all	Ethical	Overall
climatezone	0.412*					0.321
	(0.248)					(0.321)
leftrule	0.700***					0.672**
	(0.273)					(0.349)
GPshare06	11.595**					1.403
	(5.541)					(10.151)
polchange0206	0.742***					1.135***
	(0.272)					(0.365)
public	1.904***					2.060***
	(0.353)					(0.525)
maxeprice20052010		0.018		0.016		0.006
		(0.016)		(0.018)		(0.021)
diff_eprice		-0.002		-0.003		0.010
		(0.306)		(0.016)		(0.020)
exp_eprice		0.306		0.309		0.688***
		(0.202)		(0.202)		(0.248)
ren_needs		0.934**		0.939**		0.806
		(0.475)		(0.477)		(0.541)
shareMHP_scale		0.648*		0.648*		0.837**
		(0.334)		(0.339)		(0.405)
ren_MHP		-0.312**		-0.316**		-0.316*
		(0.140)		(0.137)		(0.167)
no_employed		0.005**		0.004*		-0.001
		(0.005)		(0.020)		(0.003)
market			-0.117	-0.020		-0.144
			(0.105)	(0.141)		(0.225)
metropolitan			-0.024	0.121		0.483
			(0.277)	(0.346)		(0.431)
champion					0.268***	0.273**
					(0.077)	(0.109)
Number of obs	109	93	111	93	108	91
LR chi2(14)	40.97	15.37	1.68	15.67	12.52	59.36
Prob > chi2	0.0000	0.0315	0.4317	0.0742	0.0004	0.0000
Pseudo R2	0.1934	0.0847	0.0078	0.0863	0.0594	0.3132

*, **, *** statistically significant on 10%, 5%, 1% level respectively

Looking at the economic factors, the three variables correlated with an increased probability of being more ambitious are energy price expectations, the share of Million Homes Program buildings in relation to the total building portfolio, and the renovation needs of this share. Neither relatively high, nor more volatile energy prices measured over a recent five-year period seem to be related to the probability of being more ambitious. This result remained stable when using an interval variable instead of the continuous variable for the highest energy prices. Furthermore, there is no indication that the number of employees, used as a proxy for size of the firm, is correlated to more ambitious attitudes to energy efficiency. The results remained stable when replacing the continuous variable with a variable that grouped the number of employees in different ways.

Finally, agreeing that someone(s) within the firm is pushing the energy issue, as a proxy for ethical conviction, appears to be correlated to the probability of a firm being more ambitious.

In table 6, the marginal effect of an increase in each of the independent variables on the probability of going from 1 to 2 (second column) or from 2 to 3 (third column) in terms of energy ambition is reported.

Table 6 Marginal effect on probability of becoming more ambitious of unit change in independent variables

Y = Pr(threeambtype==2/3)	**Marginal change (Standard error) y = Pr(threeambtype==2) (predict, outcome (2)) = 0.777** dy/dx	**Marginal change (Standard error) y = Pr(threeambtype==3) (predict, outcome (3)) = 0.047** dy/dx	X
climatezone	0.049	0.034	2.813
	(0.052)	(0.036)	
leftrule	0.083*	0.081	0.407
	(0.049)	(0.054)	
GPshare06	0.214	0.149	0.049
	(1.552)	(1.083)	
polchange0206	0.113*	0.152**	0.407
	(0.064)	(0.068)	
public	0.539***	0.124***	0.769
	(0.140)	(0.048)	
maxeprice20052010	0.001	0.001	71.508
	(0.003)	(0.002)	
diff_eprice	0.002	0.001	11.921
	(0.003)	(0.002)	
exp_eprice	0.105*	0.073**	1.934
	(0.055)	(0.086)	
ren_needs	0.123	0.086	2.286
	(0.093)	(0.062)	
shareMHP	0.128*	0.089*	3.220
	(0.077)	(0.05)	
ren_MHP	-0.048	-0.033*	7.571
	(0.031)	(0.020)	
no_employed	-0.000	-0.000	63.868
	(0.000)	(0.000)	
market	-0.022	-0.015	2.440
	(0.035)	(0.024)	
metropolitan	0.057	0.059	0.341
	(0.045)	(0.062)	
champion	0.042*	0.029*	3.440
	(0.023)	(0.014)	

Let's first look at the marginal impact on the probability of moving from the lowest level (SPMC, outcome 1) to the middle level (LEC, outcome 2) of increases in the independent variables. This is shown in the second column of table 6. If the firm is located in a municipality governed by SDP or the Left Party, the marginal effect on the probability of becoming more ambitious (outcome 2) from the lowest level (outcome 1) is 8.3 %. The impact is significant on a 10 % level. A change in the political majority between the elections of 2002 and 2006 has a marginal effect of 11.3 % on the probability of a move up from the lowest level, which is statistically significant on a 10 % level. The strongest marginal impact on the probability of moving up from the lowest level is being municipally owned; this increases probability by 53.9 %, which is significant on a 1 % level. The marginal impact of expecting high(er) energy price increases on the probability of being more ambitious is 10.5 %, the marginal impact of a higher share of buildings from the 1960's and 70's is 12.8 %, both significant on a 10 % level. The marginal effect of an energy champion on the probability of being more ambitious than the lowest level is 4 %, significant on a 10 % level.

Turning next to the probability of going from a little extra ambitious (LEC, outcome 2) to very ambitious (AC, outcome 3), we notice that the marginal effect of the parameter estimate of a SDP or

Left Party majority is not statistically significant on this level. The marginal effect of a change in political majority between the 2002 and 2006 elections on the probability of becoming very ambitious is statistically significant on a 5 % level. The magnitude of the impact is slightly higher than what it was for the probability of going from the lowest level to the middle level, 15.2 %. The marginal effect on going from LEC to AC of having a municipal owner is 12.4 %, which is significant on a 1 % level. Energy price expectations seem to matter also for the probability of becoming very ambitious; the marginal effect is 7.3 % which is statistically significant on a 5 % level. A higher share of Million Homes Program buildings increase the probability of being very ambitious by 8.9 % on the margin. If this large share of MHP buildings also is in need of renovation, however, the marginal impact seems to be negative by 3.3 %. Both of these variables are statistically significant on a 10 % level. Finally, the marginal impact of having an energy champion within the firm is lower at this level; it increases the probability of being very ambitious by 2.9 %, statistically significant on a 10 % level.

5.2 Discussion

Returning to the hypotheses, some factors do seem to be correlated with more ambitious firms. There are indications that a SDP or Left Party majority in the local parliament have influence on the probability of a firm being more ambitious to a certain extent, which may indicate a prosocial influence on the housing firm. It seems that a "left" majority has some impact on doing more than "business as usual", but not on the probability of becoming very ambitious.

Curiously, a change in the political majority between the local elections of 2002 and 2006, regardless of the direction of change, seems to have a relatively strong impact on the probability of moving up from both of the levels of ambition, particularly to the AC level. As the variable only captures the effect of a change between 2002 and 2006, it is hard to sort out what is going on here. In Högberg *et al.* (2009), one concern about the very ambitious firms was that a change in political majority may lead to fast new directives, with a risk of leading to renovations and energy efficiency improvements that hadn't been thoroughly analyzed and planned. If the indications here stem from a new political majority wanting to set a more pro-environmental agenda, there is of course also a risk that a shift in power in subsequent elections will result in different priorities, which may result in the withdrawal of ambitious energy efficiency plans.

The hypothesis that gains most support relates to ownership and there does seem to be a clear connection between being municipally owned and ambitious. This is in line with our expectations that public firms should be more prosocial and pro-active also on the environmental side. The estimates are economically as well as statistically significant. The stronger impact is found when going from SPMC to LEC but the impact is still large on the probability of moving to the AC level, which indicates that being a municipally owned firm is important to the probability of being more ambitious.

Among variables that influence the firms' economic conditions, expectations about future energy prices and the share of Million Homes Program buildings both seem to be correlated to the probability of moving from one level of ambition to the next, slightly more for moving to the LEC level than for moving to the AC level. Regarding energy price expectations, the direction of causality is an open question, especially since the past levels and fluctuations of energy prices don't seem to influence probability. Is a firm that expects higher energy price increases more inclined to be ambitious, or does a firm that has adopted an ambitious attitude "justify" this by expecting higher energy price increases? Although the former should be expected if the firm is rational, some of the interviews in Högberg *et al.* (2009) indicated that the latter shouldn't be surprising; some firms rather didn't make proper investment analyses for energy efficiency improvements, but were sure that the investments would pay off "in the long run". In the Swedish media debate, there have been numerous contributions arguing that the renovations of the MHP buildings is a "golden opportunity" to concurrently invest in energy efficiency improving measures, and the results here suggest that Swedish housing firms are following the same line of argument.

The larger the share of Million Homes Program to the total numbers of buildings, the higher the probability that the firm is more ambitious. A high share of MHP buildings may mean that energy consumption within the firm largely is driven by buildings from this period of construction, which should be appropriate for the firm to target. A large share of MHP buildings may also mean that many of the buildings are being scrutinized and that firms thereby discover energy saving potential. It could also be that MHP buildings have an image problem that housing firms believe they may be able to moderate by adopting a more ambitious strategy for energy efficiency improvements. The slight tendency to be less ambitious with a higher share of MHP buildings the longer ago they were renovated, interpreted as larger renovation needs, is in line with expectations. If the needs are more urgent, there may not be time to adopt a holistic perspective including a high degree of energy efficiency. Instead, firms may have to focus on plumbing repair and replacement in order to avoid damage by damp.

Two of the economically related hypotheses get no support. It is surprising that actual energy prices don't seem to influence the probability of being more ambitious, not even from the SPMC level to the LEC level. However, since we know nothing about the contract design between the housing firm and the utility firm, there may be mechanisms related to energy prices that aren't being picked up here. It may also be that the energy prices in general are low (or high) enough to not affect this probability for some firms more than others. The results may also indicate that energy taxes may be an inefficient way to address energy efficiency. The seeming absence of influence from the type of market in which the housing firm is operating, might be explained by production costs; if the local real estate market is stronger (e.g. lower vacancy rates and higher willingness-to-pay), perhaps the cost of input factors such as labor costs in renovation and energy efficiency projects are also higher, thereby offsetting such an impact. It is also a little bit surprising that firm size, as indicated by the number of employees, didn't seem to influence the probability of being even slightly more ambitious. One could expect more employees to allow more specialization, for example in the energy area. On the other hand, larger organizations may have more and higher demands from stakeholders, and depending on what those demands are, it might perhaps make it more difficult to work with this type of issue. It may also be more difficult in a larger organization to implement additional routines to business-as-usual.

Finally, in support of the last hypothesis, it seems that it may be less of a question of how many employees a firm has, and more a question of *who* the employees are. The results support the hypothesis that an energy champion within the firm pushes the energy issue. One or a few people who are truly dedicated to improving energy efficiency might be more important than 20 people who are unaware of or uninterested in energy efficiency improvements.

The usefulness of the concept of "ambitious" company

Previous studies that have looked at firm behavior related to energy efficiency have used actual investment decisions and looked at how characteristics of the firm correlates with what firms invest in and in what way. Since one of the main characteristics of the real estate sector is its durability and the risk of irreversibility of investment in energy efficiency in connection to renovations is relatively high, an ex-post approach would defeat the purpose in this study. Instead, to be able to predict housing firms' energy efficiency efforts before they carry out investments (and thereby close the renovation window, perhaps missing the golden opportunity), this study focused on firms' ex-ante ambition.

Policy intervention to encourage energy efficiency may be justified if we believe that the measures that ambitious firms carry out more accurately reflect the true level of optimal energy efficiency investments. In order for all firms to reach this level, barriers would have to be removed and stronger incentives provided. To enable timely policy intervention and increase its efficiency in outcome, we chose to study what the housing firms plan to do and how they present the firm's energy efficiency goal(s) and initiated effort as an indicator to predict the actual outcome.

Naturally, there is no guarantee that aims and ambitions result in output, but the assumption here has been that higher ambitions should predict larger actual energy savings compared to the accidental results by firms who don't have any aims. Since planning and construction processes take time, the big renovation challenge facing so many of the Swedish housing firms may have been initiated but still need several years to be completed. The findings and learnings from this study may hopefully help in designing policy tools that can be used before that time frame has passed.

6 Conclusions and policy implications

In this paper, the starting point was the observation that some Swedish housing firms seem to be taking on a very ambitious approach to energy efficiency improvements, which is somewhat unexpected given the last decades' interest in the energy efficiency gap. Taking on an inductive approach, we have used web survey data from Swedish housing firms to test six hypotheses about what might correlate with these ambitious firms. A summary of the results can be seen in table 7.

Table 7 Summary of results

Hypothesis: Firm is/has		Support
a)	municipal (1, 3),	Yes
b)	operating in a market characterized by high and/or volatile energy prices (2),	No
c)	operating in a strong market (2),	No
d)	a building portfolio in need of renovation (2),	Yes
e)	large (2), and	No
f)	an expert employee who champions the energy efficiency issue (3).	Yes

There is support for the policy-related hypothesis that being municipally owned increases the probability of being more ambitious. There is also support for the financially relevant hypothesis, that the characteristics of the building portfolio matter, a larger share of Million Homes Program Buildings increase the probability of being more ambitious whereas a longer time since the last renovation of these buildings decreases the probability of being more ambitious. The ethics-related hypothesis that an energy champion will increase probability that a firm is more ambitious also gained support. Three of the hypotheses that aimed to capture the economics of very ambitious firms were not supported by data; past energy prices, market strength and firm size did not seem to influence the probability of being more ambitious.

Taken together, the results indicate that being very ambitious isn't a profit maximizing strategy. Instead, other considerations and drivers motivate firms to act prosocially and do more than what is short-term profitable. Having a municipal owner means that the firm needs to take into consideration various demands and fulfil various goals of which profitability is but one. Being public thus can be seen as a proxy for being not profit-maximizing in this study, which is to be expected when firms face conflicting goals (Cyert & March, 1963). Some firms, public and private, see beyond short-term profitability and aim for higher energy performance, a choice facilitated by dedicated individuals within the firm, the energy champions. The energy efficiency gap will be sustained by the firms who don't fulfill these criteria, and to address these firms, additional policy tools may be necessary. One type of policy tools may be needed to make investments more financially attractive, but policy may also need to address how energy efficiency is perceived in relation to the image-concerns. Owning a large share of MHP buildings might help bring the issue up on the agenda for the firms, which might be a good start for intervention for policy makers.

The policy-related results don't exclude the possibility that in addition to national building code, the local government might be able to exert influence over a basic level of public *and* private housing firms' energy efficiency ambitions. It should be noted that the EU Directive 2012/27/EU emphasize the role of the public sector and their obligation to lead by example in energy efficiency matters. This may however be in conflict with the Public Municipal Housing Companies Act (2010:879).

That local real estate market strength and firm size seem to play little or no role in probability of becoming more ambitious means that policy makers to some extent may disregard such factors if/when trying to influence housing firms across Sweden in a more ambitious direction. Policy makers may instead try to target firms in which they believe the absolute impact would be large, for example a firm owning many square meters of space to maximize impact. The indication that actual energy prices have little impact on the probability of becoming more ambitious, should also be kept in mind, for example to be cautious about trying to influence energy efficiency work through energy prices/taxes. Finally, to advance energy efficiency, policy makers could support (the fostering of) energy champions, e.g. through informational interventions.

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Appendix A

A.1 Classification questions

The following questions were the starting point for classifying the respondents. Further assessment was shown necessary, which is described in section A.2.

C1: Has the board adopted any objectives to reduce energy consumption in your building stock?
C2: Who initiated these objectives?
C3: Do you have objectives specifically for
  a. new production?
  b. renovation?
  c. existing buildings?
C4: Do you believe you will reach your objectives?
C5: If the board has not adopted any objectives, do you work in any way particular to reduce energy consumption?
C7: Do you have guidelines saying that replacement of technical equipment (e.g. appliances or fans) should be for energy economic alternatives?
C8: In our company there are clear management directives/demands to save energy
C9: In our company there are a number of employees who push the energy matter hard

A.2 Assessment and delimitation

The study builds on the classification into ideal types, meaning there has been an individual assessment of the level of ambition. Ideal types accentuate the broad features but cannot reflect all imaginable variations, whereby some firms will not exactly fit the description of the ideal types, particularly since deeper contact has not been possible within the scope of this study. As expected, there have been cases where the classification has not been evident and there have been difficulties in the choice between SPMC and LEC as well as between LEC and AC.

The main issue in classifying SPMC and LEC has been in assessing whether a firm's expressed environmental ambition is a case of "green-wash", meaning the firm is trying to appear environmentally friendly without any ambitions to actually perform. In the assessment, it has therefore been taken into consideration if the firm has a) declared any energy savings goals or ambitions, b) mentioned energy savings merely as an economic issue, and c) provided any examples of the firm's efforts to save energy.

If energy saving has not been mentioned at all, it has been interpreted as an issue of low attention and/or priority. If energy issues are mentioned but only from a cost-savings perspective, energy savings/efficiency activities have been interpreted as something the firm does only if it is profitable in the short run. If energy issues are mentioned and described as a cost as well as an environmental issue but without any examples indicating that the firm is actively engaged in energy savings activities, it has been interpreted as a low priority issue. At any of the above interpretations, the firm has been classified as SPMC. If the firm has been able to show energy savings goals/ambitions, describes the energy issue as (also) an environmental issue that the firm needs and wants to take responsibility for and can provide examples of energy savings/efficiency work, the firm has been classified as LEC.

The main difficulty in choosing between SPMC and LEC has been when firms under b) have described their responsibility in a dutiful way, or under c) have pointed to examples that require minimal effort from the firm. To exemplify both difficulties, one can mention linking to energy savings campaigns only using official promotion material, without showing the least how this has been handled by and within the firm. Indeed, to affiliate with such campaign does indicate that the firm has reflected upon the energy issue, but not that the reflection appears to have evoked any enthusiasm or been translated into a plan or actual work to save a larger amount of energy.

A risk with this approach is that the firm simply doesn't declare their energy saving activities on the website or in other informational materials. The assumption here, however, is that firms that work actively with energy saving (beyond strictly short-term profitable actions) also understand the promotional value in declaring this, or think that it is an ideologically important message to convey. Any ambitious firms who do not communicate this are therefore assumed to not distort the results since they ought to be marginally few.

The firms that have clear, ambitious goals for energy savings in their building portfolio, and who can show credible examples of performed energy saving/efficiency work or a strategy for this have in most cases been classified as AC firms. One example of such work is the Skåne initiative, a declaration of purpose initiated by the municipality owned public housing firms' organization SABO (the Swedish Association of Public Housing Companies), with the aim to improve energy efficiency by 20 % between 2007 and 2016, a shorter period than the corresponding national goal. The Skåne initiative hasn't been sufficient or even necessary example of ambitious energy saving/efficiency work. In addition to the Skåne initiative, an assessment was made of how the energy efficiency work is progressing, e.g. by looking at annual reports.

To also have a plan for how energy efficiency work will proceed after reaching the 20 % or in other ways being able to demonstrate long-term commitment, is an example that have gotten firms into the most ambitious category. Surprisingly, this has been the case also for firms in smaller and less attractive places, where such efforts could have been expected to have low priority due to declining markets and low willingness/ability to pay. In contrast, no private firm has been classified as the most ambitious type. Private firms have no Skåne initiative to confess to, but even in the cases where more ambitious energy saving goals have been declares, the undertone has explicitly or implicitly been that this has been done with an assumption about profitability and thereby a profitability restriction (this has also been true for some public firms).

The limit has been sometimes hard to draw, since it has been unclear how extensive the commitment of the LEC firms is. Those who have declared ambitious goals have in some cases not been able to demonstrate any examples of performed or planned investments indicating commitment and engagement related to those goals. It can also be hard to assess what firms will actually stick with their goals and energy saving plans if it proves to be costly. To be ambitious when there are low-hanging fruits still to be picked is not unusual, whereas the bigger investments often require commitment, engagement and coordination. How far the low-hanging fruits will get them may be critical in how much of the ambition that will actually be realized, and this is of course hard to predict beforehand. There is of course never any guarantee that a firm that is truly an AC (or, for that matter, a LEC firm) will live up to expectations and goals, due among other things to how reasonable these goals are in relation to the building portfolio, what technology is available and what resources are dedicated to reach them. What is determining for AC firms, however, is that they stand by their commitment even if it turns out not to be (or even has proven already not to be) profitable.

In some border line cases between LEC and AC, information about new construction has been guiding. If there have been clearly specified goals for low energy use in new housing, this has been seen as an indication of the importance of the issue within the organization (even if profitability of course may differ substantially between new construction and renovation).

The not ambitious firms are expected to do only improvements that are more profitable than competing investments, i.e. not much more than savings measures and other measures with a short payback period. The somewhat ambitious firms have slightly higher ambitions for improving energy efficiency, but still need the investments to pay off, albeit with a little longer time perspective than the SPMC (and possibly considering coordination benefits from "investment packages" of measures, rather than each measure individually, as an option). Both public and private companies were found in these two types of firm. Finally the ambitious firms, all public, aim to improve energy efficiency rather radically, and profitability is not their main concern. The ambitious firms can be top-down driven, following ambitious energy savings goals set by politicians for company officials to implement, or be bottom-up driven, where primarily enthusiasts within the firm champion the energy efficiency issue. Depending on management, energy efficiency work can be initiated with short notice or taken into account early in the (renovation) planning process in a holistic manner (Högberg et al 2009).

Table A1 Correlation matrix for firm characteristics and level of ambition

		amb[1]	**treamb**[2]			**amb**	**treamb**
Org/Mgmt	allmännyttigt	0.3972	0.2723	Population	Pop06	-0.0668	-0.0806
	eldsjal	0.1459	0.1673		Pop07	-0.0666	-0.0806
	board_initiative	0.0642	0.0712		Pop08	-0.0666	-0.0806
	board_adopt	-0.3077	-0.3068		Pop09	-0.0664	-0.0807
	board_demand	0.0309	0.0423		Pop10	-0.0661	-0.0807
	mgmt_initiative	0.2637	0.3015		Pop10-Pop07	-0.0523	-0.0774
	officer_initiative	-0.0576	-0.1180		Pop_sm06	-0.0239	-0.0277
					Pop_km07	-0.0236	-0.0275
Size	antalanställda	0.1674	0.2482		Pop_km08	-0.0230	-0.0268
	antallgh	0.1071	0.1938		Pop_km09	-0.0223	-0.0255
	antalmp	0.0891	0.1921		Pop_km10	-0.0217	-0.0248
	andelmp	-0.1409	-0.1724		Pop_km_10-07	0.0065	0.0090
					Medelålder10	-0.0883	-0.1996
Condition	Nejinterenov	0.0677	0.0533		Snittinkomst09	0.0624	0.0804
	Större70tal	0.0039	-0.0589		Snittinkomst10	0.0641	0.0770
	Större80tal	-0.0365	-0.0365		Medianinkomst09	0.1190	0.1444
	Större90tal	0.0486	0.0442		Medianinkomst10	0.1297	0.1489
	Större70-90	0.0431	0.0084		Unemp2009	-0.1156	-0.1147
	Mindrelöp	-0.1037	-0.1015		Unemp10	-0.0966	-0.0929
	Nurenov	-0.2702	-0.3337		Foreign	-0.0271	0.0767
	Tungfråga	-0.0352	-0.0332		Highereduc	-0.0035	0.0725
					Elderly	-0.0826	-0.1927
Energy	FVandel	0.0002	0.0672				
	Minepris	0.0546	0.0542				
	Maxepris	0.0564	0.0290	Policy	Klimatzon	-0.0926	-0.1184
	Eprissnitt	0.0695	0.0309		Leftrule	0.0416	0.0491
	Eprisdiff	0.0157	-0.0413		Greenparty	-0.0628	0.0337
	Eprisprognos	0.1427	0.1878		Changerule	0.1470	0.2006
					Env_rank09	-0.2715	-0.2408
Market	Vacancy	0.0388	-0.0388		Env_rank10	-0.0587	-0.1292
	Aptprice	-0.0086	0.0413		Env_score	0.0185	0.0772
	Aptprice_sm	-0.0169	0.0263				
	Mun_type	0.0243	-0.0002				
	Storstad[3]	0.0976	0.0976				

[1] SPMC, LEC+AC
[2] SPMC, LEC, AC
[3] The three metropolitan areas include municipalities:
Stockholm Metropolitan Area (MA): Södertälje, Nykvarn, Nynäshamn, Botkyrka, Salem, Huddinge, Haninge, Tyresö, Stockholm, Nacka, Värmdö, Lidingö, Solna, Sundbyberg, Danderyd, Vaxholm, Ekerö, Järfälla, Sollentuna, Täby, Österåker, Upplands-Väsby, Upplands-Bro, Sigtuna and Vallentuna.
Göteborg MA: Kungsbacka, Mölndal, Härryda, Göteborg, Partille, Öckerö, Lerum, Vårgårda, Alingsås, Ale, Kungälv, Stenungssund and Tjörn.
Malmö MA: Vellinge, Trelleborg, Malmö, Svedala, Lund, Burlöv, Staffanstorp, Lomma and Kävlinge.

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The impact of energy performance on single-family home selling prices in Sweden

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Abstract

Purpose – This study aims to test whether energy performance effects single-family home sale prices. It also examines whether recommendations for supposedly cost-effective energy efficiency measures, by intervention category (construction, installation or operation/control technical measures), are perceived as untapped potential – a real option – that effects sale prices.

Design/methodology/approach – The energy performance measurement and dummy variables for three categories of improvement recommendations are included as explanatory variables in a hedonic regression analysis using transaction data and energy performance certificates data for 1,073 observations.

Findings – Results indicate that better energy performance effects selling prices positively. Energy efficiency recommendations seem to have an impact on sale price; home buyers seem to require a larger "discount" for more complex types of measures.

Research limitations/implications – The sample only includes houses in the Stockholm; so-called sustainable buildings have not been specifically studied; and the heating source has not been accounted for.

Originality/value – The EU energy performance certificates provide new information and measure energy performance more exactly than many earlier (proxy) variables. This is one of the first studies to test the effect of this information, and the first one using Swedish data.

Keywords Energy efficiency, Energy performance, Hedonic analysis, Property value, Swedish housing market

Paper type Research paper

1. Introduction

> Pay attention to the roof if you go to a show in the winter; if the snow stays it's an indication that the house is well insulated.

The above is an anecdotal example of tips shared among Swedish home buyers to assess the thermal qualities of single-family homes in order to avoid the worst "energy hogs". Another indication of energy performance is old energy bills, but yet another method has emerged since 2009. In response to the EU Directive 2002/91/EC on the energy performance of buildings (EPBD), all Swedish home owners are now obliged to

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conduct an energy performance certification (EPC) upon the sale of single-family homes. This is one step toward reducing the European building sector's current 40 percent share of total energy consumption, and one expectation is that this system will "introduce transparency for prospective owners or users with regard to the energy performance in the Community property market" (EU Directive 2002/91/EC, p. 1).

In addition to the significance of energy costs in total household expenses, the climate change debate in the last decade has brought attention to the environmental impact of buildings in property valuation. Both of these factors should influence the purchasing decisions of the ever-more-informed home buyer. Furthermore, home buyers should want to know whether the building's energy performance can be improved. EPCs include recommendations for cost-effective measures that can be implemented to improve energy performance. Since these recommendations also inform buyers of the building's potential performance, these ways to improve energy efficiency signalled through the EPCs could increase the house owner's/seller's incentive to undertake more energy efficiency investments.

By using a hedonic price model, transaction data and Swedish EPC data, the aim of this study is to investigate the effect of building energy performance on single-family home selling prices. The data is new, and EPC data has not been used before to study this relationship in a Nordic context. The study also examines whether suggested measures for improving energy efficiency in terms of intervention type (construction, installation or operation/control technical measures) have an impact on selling prices. The hypothesis is that for a given level of building energy consumption, the existence of recommended measures for improvement should be an element that increases the selling price, as this information would indicate potential energy savings, i.e. a real option. A wider aim of the study is to contribute to better market valuation of the energy-related properties of single-family homes.

The paper begins with a literature review in Section 2 and a brief overview of the EPC system in Section 3. Section 4 describes the methodology and data, and the results are presented in Section 5. These results are discussed in Section 6, and Section 7 gives the conclusions.

2. Literature review

Sweden has adopted ambitious energy efficiency targets and energy standards in building codes that are relatively strict (Prop. 2008/09:163; Boverket, 2009a; OECD/IEA, 2008). Swedish home owners, however, have been reluctant to invest in energy efficiency measures. In a 2008 survey of Swedish home owners, fewer than 30 percent said they planned to undertake building envelope measures (new windows, attic insulation or wall insulation) to improve energy efficiency within the next ten years (Nair *et al.*, 2010). When choosing among energy efficiency measures, home owners named annual energy cost savings and initial investment as the most important factors. Notably, increasing market value was not seen as particularly important in choice of measure; nor were other aspects related to the measures, such as environmental benefits, ease of installation, greenhouse gas reductions or time required to collect information The study, while not related to the home buying (or selling) decision *per se*, still indicates that energy efficiency was not perceived to be reflected in market value.

The EPCs bring new information to actors in the housing market. The first preliminary evaluation of the EPC system in Sweden was carried out by the National

Board of Housing, Building and Planning (NBHBP), the authority responsible for implementing the EPCs. In their telephone interviews with 100 home buyers, 18 said the EPC made a difference in their choice of a house, but also suggested that the information may have come to their attention too late in the process. For 60 of the buyers, the EPCs included recommendations for improvements, which the seller had already attended to in one-fifth of the cases. Out of the 60 buyers who had been advised to make improvements, almost 80 percent said they already knew about the recommended measures; 62 percent perceived the suggested measures to be profitable; and 60 percent had carried out or planned to carry out one or all of the suggested measures (Boverket, 2009b).

Many hedonic studies have looked at the effect of energy efficiency on home selling prices. Three main types of energy efficiency indicators have been used as explanatory variables: specific attributes, fuel type and energy bills. Only a few recent studies have used measured energy performance, and a large portion of the literature is growing old.

Overall, study results indicate that attributes associated with a more energy-efficient home, such as storm windows or thermo pane glass, better insulation or central heating, lead to a higher transaction price (Laquatra *et al.*, 2002; Brounen and Kok, 2011; Banfi *et al.*, 2008; Berry *et al.*, 2008; Wilhelmsson, 2004). However, the magnitude of the effect is difficult to compare as the employed study methods differ. Moreover, it is sometimes unclear what effect specific attributes actually measure, making it hard to compare results and claim they measure the same thing (energy efficiency). For example, instead of being viewed as an energy savings, installing a single level mixer in the shower could impact selling price because it is perceived as a bathroom renovation (Wilhelmsson, 2004), or the effect of better windows on price could be because they are perceived to reduce noise (Berry *et al.*, 2008).

Energy efficiency related to fuel type may have an impact on selling price for several reasons, including perceived uncertainty due to fuel price volatility, relative environmental impact or ease of maintaining the system using the heat source. In one of the studies reviewed by Laquatra *et al.* (2002), natural gas heat instead of oil heat led to an increase in market value of US$4,597 (in 1975), but the effect did not last over time. Wilhelmsson (2004) found that direct electric heating negatively impacted the selling price by approximately 7 percent, whereas having a heat pump in general did not have a statistically significant impact on price.

As an example of studies using energy bills as the independent variable, a $1 decrease in annual energy/utility bills has been shown to increase home values by US$11.63-US$20.73 (1980s) (Laquatra *et al.*, 2002). As noted by Laquatra *et al.*, however, using utility bills as the independent variable can be connected to endogeneity problems, as lifestyle differences may influence both energy consumption and home value. In Swedish home sales, energy costs are commonly reported, but information asymmetry further complicates matters; there is no way for the buyer to determine if low energy bills are the result of an energy-efficient home or of the previous owner's "Spartan" way of life. In addition, the varying effect of fuel type as well as household attributes (such as environmentally aware or informed households) found in Wilhelmsson (2004) indicate that energy cost is just one of the mechanisms through which energy efficiency potentially influences selling prices.

Two recent studies use more explicit measures of energy performance. In the Capital Territory of Australia, thermal qualities of buildings have been reported since the 1990s in a system that can be said to be a predecessor of the EPCs. Energy performance was measured and rated on a six star scale, and Berry *et al.* (2008) hedonically studied the relationship between energy performance and detached house prices in samples of 2,385 and 2,719 houses for 2005 and 2006, respectively. The main results were that house energy ratings (HER) had a positive relationship with price: for each 0.5 HER star, selling price increased by 1.23 percent in 2005 and by 1.91 percent in 2006.

In the second study, Brounen and Kok (2011) did the first empirical investigation of the large-scale labelling program that is the EPCs. Overall, they suggest a price premium of up to 15 percent of selling price for energy-efficient homes in the Dutch housing market. Starting in 2008, The Netherlands were early adopters of EPCs, and the semi-mandatory nature of their system enabled a natural experiment. To control for self-selection bias – that home owners with a certain type of home were more likely to certify their buildings – the hedonic analysis was based on a two-step Heckman model used on a sample of 32,000 certified dwellings of all types. From A-rated to G-rated homes, Brounen and Kok estimated a steadily decreasing price premium, where A-rated homes sold at 10.2 percent higher and G-rated homes at 5.1 percent lower than the F-rated baseline homes. In addition, homes with a "green" label (categories A-C) sold at on average 3.7 percent higher, *ceteris paribus,* than other rated (categories D-G) homes, and at 3.6 percent higher when also controlling for building quality. The decreasing price premiums seem to correspond to the present value of future energy savings resulting from improved energy efficiency, but also to reflect something more than energy savings. The EPCs themselves have been criticized in The Netherlands. Brounen and Kok test whether the price premium has been negatively impacted over time due to decreasing consumer confidence but suggest that the variation they found in price over time reflects differences in media reporting. The authors also suggest that sellers use EPCs to resolve the asymmetric information problem in high competition areas, rather than to signal superior quality. Additionally when studying the mix between energy-related attributes and actual energy performance[1], Kok and Kahn (2012) show that homes labelled "sustainable" in California on average sell for up to 14.5 percent more than unlabelled homes.

In the study by Brounen and Kok, the correlation between price premium and future energy savings seems to indicate that property markets do capitalize on the value of energy efficiency investments. The hypothesis of rational market valuations for home energy efficiency has gained empirical support, both in terms of what home buyers are willing to pay and how appraisers value energy efficiency investments (Nevin and Watson, 1998; Nevin *et al.*, 1999; Popescu et al., 2009a, b). Entrop *et al.* (2010) used the EPC information to show that, as long as the property value of a building increases, the payback time for energy efficiency investments can be shortened, and that payback time was shorter when indirect benefits from increased property value was included in calculations. However, Dubin (1992) has argued that implicit discount rates for energy efficiency resulting from hedonic estimations are overestimates because they are reached under the assumption that home owners will not move from the house, but rather will capitalize all of the investment cost themselves. Dubin combined results from hedonic studies with a method of probabilistic choice and concluded in his theoretical model that the implicit discount rate depends on the degree of capitalization of energy efficiency improvements and on the probability of moving. Therefore, the discount rate is likely to be lower than it is in the earlier reports. In his discussion, Dubin also mentioned that capitalization rates in general should be higher in colder climates compared to more moderate zones.

To sum up, earlier studies have found a positive relationship between energy performance and selling price. However, it is not always clear what mechanisms are at play when home owners make decisions related to energy standards and related features. Possible factors that may impact the decision include energy costs and the initial investment cost, but also uncertain future energy prices, ease of finding information, ease of installing and maintaining systems and environmental benefits. By adding new information to the market, the EPCs are expected to resolve some of the information asymmetry related to buildings and energy performance. This in turn, if recognized by home buyers, should impact selling prices so that more energy-efficient homes sell at higher prices than less energy-efficient homes, all else being equal.

3. Energy performance certificates

Following the EPBD, all EU members are required to carry out an energy assessment of building stock. EPCs are a tool for assessing a building's energy performance and for informing concerned individuals and the public about possible improvements in the building performance.

EPCs for single-family houses are required when the house is new, up for sale or rent or the home owner so wishes. A Swedish EPC is valid for ten years and reports information about:

- home owner;
- location (including information for identification);
- building age;
- actual energy consumption;
- distribution of fuel sources;
- electricity use;
- existence of solar panels;
- ventilation control;
- air conditioning system;
- radon content (Bq/m^3);
- recommended improvements; and
- (if the building was assessed earlier:) what measures have been carried out since the last assessment (Boverket, 2009b).

A physical EPC assessment is carried out by a qualified, accredited assessor at the initiative of and together with the home owner. The assessor then models the energy consumption using values from the building inspection, which results in a value for the building's standardized primary energy consumption for average climate and household conditions. The results are reported to the home owner and to the NBHBP.

EPC results are communicated throughout Europe with some national differences. Sweden has chosen to present performance on a continuous scale and rating that is figurative. However, comparison values for similar (age-, location- and design-wise) and new buildings (current building code) are also included for reference. The reported energy performance is expressed as "standard consumption" (kWh/m^2/year), and the lower this amount, the better the energy performance. Once again, however, it should be stressed that this measure is standardized and should not be confused with self-reported energy consumption or energy consumption calculated through energy bills, both of which are affected by consumer behaviour.

As part of the assessment, the assessor looks at what parts of the building could be altered to improve the energy performance. The assessor can only recommend realistic and cost-efficient measures, i.e. measures that would be financed by the projected energy savings within the expected life of the investment. The measures are grouped into three categories, which can be seen in Table I.

Construction technical measures generally require quite a bit of physical intervention. Installation technical measures also require some physical intervention, but typically less than the construction technical measures. However, this amount of intervention varies with the type of measure and building circumstances. For example, replacing an oil boiler with a geothermal heat pump would probably require more work than adding attic insulation. Operation and control technical measures usually require less extensive intervention than the other two categories (Boverket, 2009b).

4. Theory, model and data

4.1 The hedonic price model

The hedonic price model for a market with differentiated goods developed by Rosen (1974) is still extensively employed to decompose home prices. The idea is that a home's selling price is a function of its attributes, and the hedonic regression reveals preferences for and implicit (marginal) values of these attributes. For single-family homes, the factors effecting selling prices can be divided into five broad categories: property specific attributes, neighbourhood specific attributes, location specific attributes, societal factors and individual circumstances. The first two categories mainly concern the actual property and its closest surroundings, such as housing area, lot size, age, accessibility, public transport and view, whereas the last three categories concern more over-arching factors that determine the conditions of the housing market, such as the type of city/labour market, land related jurisdiction, household composition and income.

These relationships are modelled in equation (1):

$$y = \alpha + \beta_1 X + \beta_2 N + \beta_3 M \qquad (1)$$

where y is the price of the property, vector X represents the property specific attributes, vector N the neighbourhood specific attributes, and vector M the surrounding

Table I. Recommended energy efficiency measures in EPCs, by type

Category of measure	Area of intervention	Typical recommendations
Construction technical	Building envelope	Sealed glazing window units, additional insulation (attic joist, floors and even the entire building), sealing heat leakages
Installation technical	Installations	Replacing heating source (in particular electricity or oil with some kind of heat pump), water saving measures
Operation and control technical	Optimization	Indoor temperature sensing for control, replacing manual radiator valves with modern thermostat valves

factors on the macro level. Estimating equation (1) is the basic step for revealing what effect (if any) different factors have on selling price. A number of general problems are associated with using the hedonic model, e.g. assessing the extent to which buyers have access to and are able to value information about features of the building and to measure and report such features (the failure of which could result in omitted variable bias, see below).

To highlight the main question, energy performance is extracted from the other property specific attributes and modelled separately in equation (2), where E denotes energy performance. The main objective is to estimate β_4, that is, to estimate the effect of energy performance on selling price:

$$y = \alpha + \beta_1 X + \beta_2 N + \beta_3 M + \beta_4 E \quad (2)$$

Moving further, equation (3) extracts the energy performance improvement potential, denoted I. Estimating β_5, the effect on selling price of such improvement potential, is the second objective of this article:

$$y = \alpha + \beta_1 X + \beta_2 N + \beta_3 M + \beta_4 E + \beta_5 I \quad (3)$$

4.2 The econometric model

Given the logic presented in Section 4.1, the model used to investigate the question at hand will be described here. The starting point is the results presented in Wilhelmsson (2004), where factors that have a price impact in the Swedish housing market were estimated. A log-linear form is chosen to enable elasticity interpretation. The dependent variable is thus the logarithmic form of selling price (first expressed in thousand SEK) for single-family homes.

The building specific variables, vector X above, are *building area*[2] *lot size* and *lot size squared*, all in logarithmic form. Intuitively, the first two variables are expected to have positive signs; the more square meters, the higher the selling price, while *lot size squared* is expected to have a negative sign reflecting the decreasing marginal utility of additional square meters. As a measure of building quality, the Swedish Tax Agency's *quality index* variable is included to account for various attributes and the condition of the building. The variable is measured on an ordinal scale ranging from 0 to 61. The better the condition of the building, the higher the value, so the expected sign is positive. This variable is partly related to energy performance; one of the five assessed aspects is energy economy[3] However, the 12 maximum points for this aspect are fairly standard in the Swedish context; points are awarded for installed electricity, insulation, double- or triple-glazing windows and an installed heating system. Only the three additional points for recent replacement of the electrical system are likely to make the assessment higher (SKV A 2008:7). A house with low scores in the energy-economy aspects most likely also performs poorly in energy efficiency, but the low number of such homes in our sample makes them unlikely to bias estimations. Furthermore, as can be seen in Table II, the aggregated quality index is only weakly correlated with energy performance. The variable *age* is measured by construction year, and is thus expected to have a positive sign; a higher value (a newer house) is expected to lead to a higher selling price, *ceteris paribus*. However, *age squared* is included to control for the fact that older buildings are often considered to possess a certain charm and are thus expected to have a negative sign. The final variable in X is *detached*, a dummy variable

Variable	Mean	SD	Min.	Max.
Sales price (kSEK)	4,128.470	1,801.754	1,250	17,000
Area (m^2)	127.350	35.945	48	360
Lot size (m^2)	531.627	285.897	90	1,763
Quality index	28.103	3.833	19	52
Age (construction year)	1,956.110	17.991	1929[a]	2006
Detached house	0.596	0.491	0	1
Standard energy consumption (kWh/m^2/year)	130.778	63.389	13	600
Operation and control technical measure	0.179	0.383	0	1
Installation technical measure	0.557	0.497	0	1
Construction technical measure	0.367	0.482	0	1

Note: [a]Buildings in the sample constructed before 1929 had already been assigned 1929 as construction year as a default value upon delivery of data

Table II. Descriptive statistics

indicating that the building is separate, as opposed to attached houses of any kind (e.g. row houses and semi-detached houses). This variable is important not only in itself, but also to control for the fact that energy consumption is influenced by whether the house is detached or not. This variable is expected to have a positive sign, as it is assumed that people in general appreciate privacy.

Finally, the variables relating to energy performance, E, are included in the model. As previously noted, the energy performance of a building directly effects household income positively through energy bills (the lower the consumption, the lower the bills). The importance of this effect depends on how home owners perceive and predict current and future energy prices. Following the climate debate in the last decade, it has come to general attention that a building's energy performance also effects the degree to which it contributes to climate change[4]. In addition, because energy prices may be volatile, a more energy-efficient house can also be seen as insurance against future energy price increases. Given these three factors, it can be assumed that a more energy-efficient house should have a higher selling price. In the econometric model, the energy performance variable, *energy consumption*, is based on the modelled "standard consumption" reported in the EPCs. The variable is in logarithmic form and is expected to have a negative sign as better performance (lower consumption) should lead to higher selling prices, *ceteris paribus*. The EPC can be seen as a proxy for energy cost which is unobservable because energy bills were not possible to collect and direct measurements of energy use were also not available. Actual data would in any case be problematic as it also reflects the household behaviour as discussed in Section 2 above.

The neighbourhood specific factors, vector N, are captured by dummy variables *o1-o87* for each "value area" as categorized by the Swedish Tax Agency. The value areas are classified after taking into account similarity in the surroundings such as sea view, noise levels and distance from the city centre. In total there are 86 value areas with non-zero observations, out of which one randomly serves as the default area. As all of the observations are from the municipality of Stockholm, no variables are included to control for macro-level factors, vector M; the observations are all assumed to be affected similarly by the type and state of the economy and the political system.

In the next step, the measure for "untapped potential" – the EPC recommendations to improve energy performance – is included as three dummy variables.

These variables represent vector *I* in equation (3). Each variable corresponds to one of the aforementioned categories: operation and control technical, installation technical and construction technical energy efficiency measures (denoted *operation control*, *installation* and *construction*). If a recommended measure (or several) falls into any of the three categories, the corresponding dummy will take on the value 1. If no recommendation fits into the category, the dummy will take on the value 0. The categories are not mutually exclusive; depending on the recommendations, anything from zero (no recommendations) through three (one or more recommendations in each category) are possible outcomes for these three dummy variables. Given the energy consumption of a specific building, the possibility to improve energy performance should be seen as something positive if the actors are rational, since it offers a real option (but not an obligation) to improve energy efficiency. However, improving energy performance is not always an easy (or cheap) task. The construction technical measures are assumed to be more extensive in nature whereas the operation and control technical measures are minor and require little interference to the building. Depending on the type of intervention, installation technical measures can be more or less interfering. Because of this assumption about untapped potential, the expected sign is positive, but the extent and cost of the measures leaves the question somewhat open. A complete list of variables can be found in Appendix 2.

A word of caution should be noted: to be able to explain the variation in selling price that is caused by energy performance, all other factors that also effect selling price should be controlled for. In this case there is one variable, *design*, that may have an effect on selling price but also potentially effects energy performance. A house designed by a well-known architect may have an extra price premium as a result. But a well-designed home may also have extra carefully designed and cared for energy-related features that result in lower energy consumption and make the house more attractive in general. The price effect could thus be attributed to the low energy consumption when the premium should really be attributed to the design factor. On the other hand, attractive but (energy) consumption-driving features of a building, e.g. panorama windows, would have the opposite effect. If either case is true, the omitted variable bias may lead to overestimation of the energy performance effect in the first scenario and understating it in the second scenario. However, in this model, the assumption is that the age variable captures most of the possible "design" effect, given the prevailing building norms when the house was constructed. Furthermore, the quality index variable should take up some of this potential effect as a designed house could be better maintained, thereby raising the quality index score. A related matter is the case of third-party-certified high-performance buildings, such as LEED or Passive Houses. It is possible that such buildings are included in the data set, but as these building have not been specifically reported because third-party certification is a rather new phenomenon, they cannot be controlled for. Nevertheless, the age and quality index variables should catch some of their effect if they are present because these buildings need to be high standard to meet third-party requirements. That said, the time has come to describe the data.

4.3 Data

For the purpose of this study, data from two sources have been combined into one cross-sectional data set. The first source is the Swedish company Värderingsdata ("Appraisal data") which collects information on all Swedish house transactions.

The data received for this study contained all transactions for single-family houses that took place in the municipality of Stockholm, Sweden, in 2009. A larger sample including other geographical areas would have been desirable, but was not possible to acquire for this study. A map of the studied area can be found in Appendix 3. Among the characteristics included in the data set are selling price, building area, lot size, x and y coordinates and a quality index for the building (see Appendix 2 for a description). The second data source is the NBHBP, the authority responsible for implementing and surveying the EPCs. The NBHBP compiles all the information collected through the EPCs, which includes energy performance, reference values, suggested improvement measures and measured energy consumption distributed by fuel type. It is possible that so-called high-performance, sustainable/green type buildings (certified by third party) are included in the final sample. Unfortunately, their presence can neither be confirmed nor rejected as the data does not report this information. The two data sets were matched based on addresses, and the final data set contains 1,073 observations. Table II shows an overview of the data.

The average selling price for the houses in the sample was just above 4 million SEK, with observations ranging from 1.25 to 17 million SEK. The average building area was 127 square meters, and the average lot size was 531 square meters. The quality index points ranged from 19 to 52 points with an average rating of 28.1. Approximately, 60 percent of the homes in the sample were detached houses. Concerning energy features, the sample showed a wide range in energy performance from a minimum of 13 kWh to a maximum of 600 kWh per square meter and year. The average energy performance/standard consumption is 130.8 kWh per square meter and year[5]. Finally, 18 percent of the houses had been recommended operation and control technical improvement measures; 56 percent had been recommended installation technical measures; and 37 percent had been recommended construction technical measures (again, the categories are not mutually exclusive).

As can be in Table III, price is relatively highly correlated to *area*, *lot size* and *detached*, and, somewhat surprisingly, negatively correlated to *age*. It seems that in this case, older charm has a stronger effect than new construction. Energy performance is negatively correlated to building size, but has a low correlation with age, which is surprising as older buildings would be expected to have poorer energy performance. Also, correlation is weak between energy performance and the types of improvement measures suggested, and even shows a negative relationship between energy performance and installation technical measures.

5. Results

5.1 The basic model

The hedonic regression of housing attributes on selling price, excluding energy-related characteristics, can be seen in the second column (OLS1) in Table IV. All continuous variables including price are estimated in logarithmic form. The error terms suffered from heteroskedasticity which is corrected for in all of the regressions. All the coefficients are significant at the 1 percent level, and all but *age* have the expected signs. However, as noted in Section 4.3, this unexpected correlation is most likely due to the "old charm" effect mentioned earlier.

In the first model, area has the largest marginal economic effect; a 1 percent increase in area (square meters) increases selling price on average 0.44 percent. The older the

Table III.
Correlation matrix

	Price	Area	Lot size	Quality index	Age	Detached	Energy performance	Control/operation	Installation
Area	0.482								
Lot size	0.480	0.341							
Quality index	0.216	0.332	0.169						
Age	−0.497	0.130	−0.337	0.167					
Detached	0.634	0.116	0.614	0.128	−0.524				
Standard energy consumption	−0.104	−0.201	−0.032	−0.123	−0.119	0.050			
Control/operation	−0.044	−0.065	−0.048	−0.103	−0.071	−0.047	0.046		
Installation	0.015	0.035	0.042	−0.029	−0.073	0.043	−0.045	0.005	
Construction	−0.089	−0.040	−0.024	−0.029	−0.061	−0.004	0.060	0.174	0.185

Dependent variable: price	OLS1, robust[a]	OLS2, robust[a]	OLS3, robust[a]
R^2	0.8922	0.8949	0.8977
Constant	319.34360 (4.59)	307.16520 (4.43)	290.74990 (4.29)
Area (ln(*area*))	0.43794 (17.75)	0.42361 (17.26)	0.42670 (17.48)
Lot area (ln(*lot*))	1.80×10^{-07} (4.00)	1.74×10^{-07} (3.91)	1.69×10^{-07} (3.76)
Lot size square (ln(*lot* ^{2}))	-4.96×10^{-14} (−2.63)	-4.72×10^{-14} (−2.52)	-4.55×10^{-14} (−2.39)
Quality index (*qualityindex*)	0.00776 (5.77)	0.00741 (5.50)	0.00705 (5.30)
Age (*age*)[b]	−0.31988 (−4.50)	−0.30758 (−4.34)	−0.29064 (−4.19)
Age squared (*age* ^{2})	0.00008 (4.50)	0.00008 (4.34)	0.00007 (4.19)
Detached (*detached*)	0.14086 (6.99)	0.14642 (7.38)	0.14556 (7.36)
Standard energy consumption (*energy performance*)		−0.04455 (−4.46)	−0.04406 (−4.52)
Operation/control (*operation control*)			−0.02429 (−2.22)
Installation (*installation*)			−0.02319 (−2.67)
Construction (*construction*)			−0.02695 (−2.94)
$O_{1\text{-}87}$	Yes	Yes	Yes

Notes: [a]Breusch-Pagan/Cook-Weisberg test for heteroskedasticity resulted in a χ^2 of 5.13; [b]Age when included as a dummy variable for each decade did not turn out to be significant; hence correcting using White's heteroskedasticity-consistent standard errors (White, 1980); models were all tested for spatial autocorrelation, but no such autocorrelation was found; as an example using five, ten and 15 neighbours for model 2, the resulting Moran's *I* statistics were 0.70487, 0.69353 and 0.70426, respectively; *t*-values in parenthesis

Table IV.
Regression results

house is, the higher the price, but at a decreasing rate. A detached house sells for 14 percent more than an attached house, and a higher score on the quality index has a small but positive marginal effect on selling price, *ceteris paribus*.

5.2 The effect of energy performance related variables on price

The addition of the energy performance variable to the regression can be seen in the third column of Table IV (OLS2). The energy performance estimate is significant on the 1 percent level, and the results indicate that for a 1 percent reduction in standard energy consumption, the marginal increase in selling price is 0.04 percent on average. This means that for the average sample house, a 10 percent improvement in energy performance (a reduction in standard energy consumption from 130.8 to 117.7 kWh per square meter and year) would increase the selling price by 18,392 SEK. Assuming the household has a monthly energy bill of 1,000 SEK[6], this improvement would yield a capitalization rate of 7 percent, which seems reasonable. This result supports the hypothesis that better energy performance should lead to higher selling prices of single-family houses. Adding the energy performance variable marginally increases the explanation power; coefficient estimates are essentially the same; signs remain the same, and estimates are still significant on the 1 percent level.

In the final step, the three types of improvements are added to the regression. Given a certain level of energy performance, if recommendations are seen as untapped potential, the three dummy variables representing the measures categories should have a positive sign; the advice on what to (cost-effectively) improve would increase selling price. However, when examining the fourth column of Table IV (OLS3), all of the three types of measures have negative signs, with significance levels of at least 5 percent. This indicates that the associated hassle of carrying out energy efficiency improvements may be seen as a burden that requires a price discount, despite the presumed cost efficiency of the measures.

Given the negative impact estimated above, perhaps it is only logical that the more uncertain of the three variables estimates appears to be for operation and control technical measures (significant at the 5 percent level). The measures in this category are comparatively easier to implement, so if effort is what drives the effect on price, and the effort in this case is low, its effect on selling price may be smaller. Home buyers nonetheless seem to require a discount of 2.4 percent of the selling price if the EPC includes recommendations for such interventions.

On the other hand, the estimates of the other two variables appear to follow a logical order, where the estimate for installation technical measures, −2.3, is lower than the estimate for construction technical measures, −2.7. Installation technical measures would require some effort from the home owner, and therefore it would make sense that home buyers require a discount. Depending on the type of intervention, the effort may be more or less extensive and hence call for more or less of a discount of the selling price. Furthermore, perhaps installation technical measures were already considered even before seeing the EPC, thereby reducing psychological barriers. One possible explanation could be that replacing oil heat with an alternative source is widely carried out in Sweden partly due to earlier governmental subsidies, hence making it a known and accepted intervention despite the associated trouble. Construction technical measures, on the other hand, require more intervention as they primarily effect the building envelope, thereby driving up the required discount.

6. Discussion

Swedish home buyers do seem to take into account the information about energy performance that the EPCs offer and attribute a price premium to energy efficiency, which is in line with earlier general conclusions (Laquatra *et al.*, 2002; Dubin, 1992; Nevin and Watson, 1998; Banfi *et al.*, 2008; Wilhelmsson, 2004) but also with early indications of the EPC system in particular (Brounen and Kok, 2011). As suggested by the evaluation carried out by NBHBP (Boverket, 2009b), not all of the home buyers had the information early enough in the buying phase for it to impact outcome. But given increasingly aware home buyers, this effect may be greater in the future. This possibility, however, presupposes that the assessments are well performed so that buyers trust the information to be accurate and valuable, which according to the early evaluations did not seem to be the case for all home buyers (Boverket, 2009b; Riksrevisionen, 2009). Accordingly, Brounen and Kok (2010) expressed concern that this scepticism may lead to home buyers losing confidence in the EPC system, undermining its value as a carrier of information.

The results indicate that home buyers do not necessarily view suggested improvements as untapped potential. Rather these suggestions seem to be perceived as a burden, and home buyers require compensation accordingly. This conclusion somewhat contradicts Dubin (1992), who argued that the capitalization rate of energy efficiency investments would be lower if one takes into account the probability of moving – that is, unless buyers are thinking in terms of reselling. Nonetheless, EPC recommendations should be valuable information to the seller, whose incentives to carry out energy efficiency investments are thus strengthened.

The more extensive the intervention, the greater the required discount appears to be, at least when comparing the estimated effect for installation technical measures and construction technical measures. In this comparison, the first type of measures induces a smaller price discount than the latter. The magnitude of the required discount for operation and control technical measures seems to be in between the discounts for installation technical and construction technical measures. This finding is somewhat surprising, but different recommendations within the three categories may imply different levels of effort (and also different investment costs and energy savings). The variable itself does not say anything about how extensive or how many measures are included among the recommendations; hence variation within these variables could lead to different impacts on buyers. Given the required cost effectiveness of the recommendations, perhaps assessors refrained from suggesting more extensive measures and instead suggested several smaller measures, making it appear as if the house requires much work. Also, home buyers/owners may value payback time and initial investment cost differently than the assessors. Seen from the seller's point of view, payback time and capital cost should be less of a problem as long as markets accurately capitalize their investment upon sale.

It is not known whether the more energy-efficient houses in the sample are so because energy efficiency improvements had been performed in them earlier or because of better initial quality and/or conditions. However, buyers have the information in the EPCs about energy efficiency measures performed earlier, which may play a role; if measures that were already undertaken are seen as "low-hanging fruits", the measures left to carry out might be the more extensive ones, which would require a greater discount. Deeper studies of EPCs than were possible in this study would be required to know what types of measures are left to carry out.

One weakness of the model is that all the houses in this sample are treated alike irrespective of heating source. The type of heating source installed may be important both for environmentally aware home buyers and for cost aware home buyers. Future studies could build upon the results of this study to determine whether different fuel types result in different effects of energy performance, either because of their environmental value or because of the different prices of different fuel types.

Another interesting question for further research would be to look at a larger geographical sample to see if there are regional and climate-related differences in Sweden similar to what Dubin (1992) suggested. The average energy consumption of single-family homes in Stockholm is lower than that of homes in the whole of Sweden (Energimyndigheten, 2011), hence the impact of energy efficiency on price could be greater in other parts of the country. As more studies are carried out in the EU, it will of course, be interesting to see if the effect of EPC information on selling price differs throughout Europe.

Some energy efficiency improvements add to the Swedish Tax Agency's quality index score, which in turn increases the home owner's property tax. There is currently a property tax cap in Sweden, but this has not always been in place and will not necessarily continue in the future. It would therefore be interesting to know whether home owners perceive the trade-off between improving energy efficiency and paying higher property tax, as the principle is still valid below the tax cap. At least the results of this study indicate that improved energy efficiency can lead to a higher market value, which perhaps offsets the possible effect of higher property tax. Results from these price estimations could also be coupled with the effect of subsidies for energy efficiency measures in order to evaluate the efficiency of the system.

7. Conclusions

This study has investigated the effect of energy performance on single-family home prices using a hedonic price analysis. The results indicate that home buyers do take into account the information available in the EPCs and put a price premium on energy efficiency. The marginal effect of a 1 percent decrease in standard energy consumption is an increase in selling price by an average of 0.044 percent. However, energy efficiency recommendations require a discount on the selling price. Suggestions in the category operation and control technical measures on average lower the selling price by 2.4 percent; installation technical measures on average lower the selling price by 2.3 percent; and construction technical measures on average lower the selling price by 2.7 percent. The overall conclusions on the effect of energy efficiency on selling price support earlier findings. The latter findings, that home buyers require discounts for suggested improvements, imply that sellers should have strong incentives to improve energy efficiency prior to selling in order to reap the price premium rather than lose the value of the discount. Suggestions for further elaboration of the results include distinguishing between fuel types, using a sample covering a wider geographical area and examining relationships with interrelated institutional factors.

Notes

1. A "mix" because some of the labels also rate other attributes, and the energy performance measure is not absolute.
2. Including all of the living area plus 20 percent of the nearby area that can be reached from within the house.
3. The other four areas are exterior, kitchen, sanitary and other interior.
4. Again it should be noted that in this aspect, the choice of heating source is also influential.
5. The minimum energy efficiency requirements for new buildings with heating other than electric heating in Sweden in 2009 was 110 kWh per square meter and year in NBHBP's climate zone III to which Stockholm belongs.
6. The average house in Sweden in 2009 consumed 13,480 kWh for heating, and the average energy price for district heating in 2009-2012 was 0.7027 SEK or 0.7464 SEK, depending on how the average price was weighted (Energimyndigheten, 2012; Svensk Fjärrvärme, 2012).

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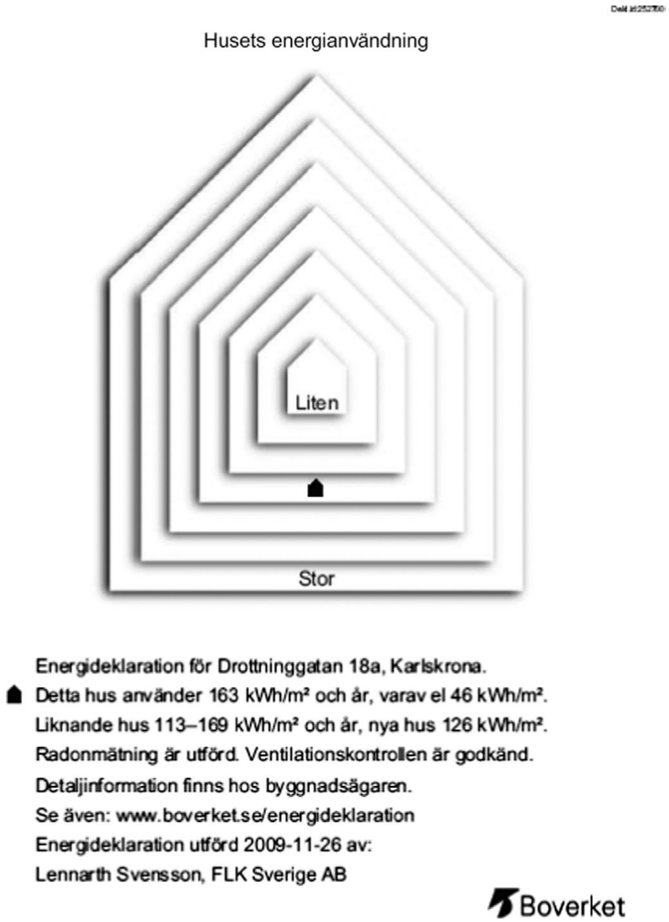
Appendix 1



Translation
Energy consumption of the building

Small
Large

Energy Performance Certificate for [address].
This building consumes 163 kWh/square metre and year, out of which electricity 46 kWh/square metre.
Similar buildings consume 113-169 kWh/square metre and year, new buildings consume 126 kWh/square metre.
Radon measuring performed. Ventilation control is approved.
Detailed information can be found with building owner.
See also: www.boverket.se/energideklaration
Energy assessment performed 2009-11-26 by:
[Qualified, accredited assessor]

Figure A1.
Example of energy performance certificate in Sweden (Boverket)

Appendix 2

Variable	Variable name	Measurement unit	Expected sign	Data source
Sales price	price	Thousands of SEK		Värderingsdata
House area	area	Square meters	+	Värderingsdata
Lot size	lot	Square meters	+	Värderingsdata
Lot size squared	lot^2		–	
Quality index[a]	quality index	Score 0-61	+	Värderingsdata
Age	age	Construction year	+	Värderingsdata
Age squared	age^2		–	
Detached house	villa	1/0		Värderingsdata
Energy performance	energy consumption	kWh/m^2/year		NBHBP
Suggestion for operation and control technical measure	operation	1/0		NBHBP
Suggestion for installation technical measure	installation	1/0		NBHBP
Suggestion for construction technical measure	construction	1/0		NBHBP
Value area	O_{1-87}	1/0 if in area		STA

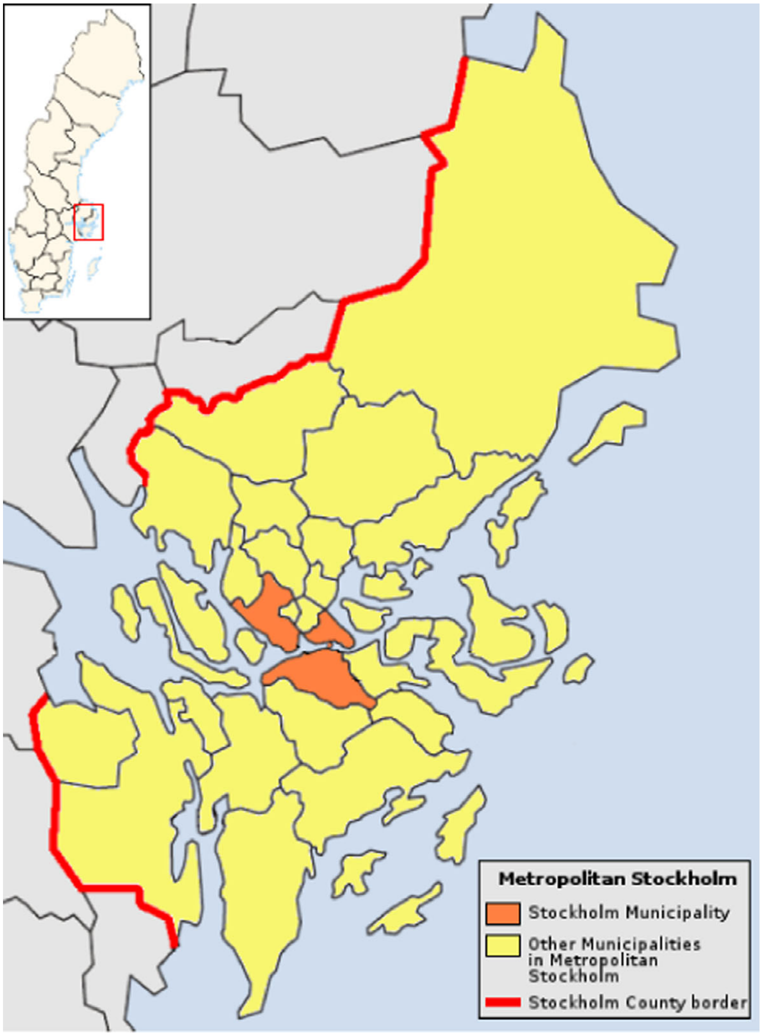
Notes: [a]The quality index variable is used in property valuation for taxation purposes; the index sums up points given for value enhancing features of the house; the 61 points are distributed over five categories: exterior, kitchen, sanitary and other interior; points are awarded according to Table AII
Source: SKV A (2008)

Table AI. Description of variables

Exterior	*16*	*Sanitary*	*16*	*Energy economy*	*12*
Frame	1	Water	2-3	Electricity	3
Façade	3-4	WC	2	Insulation (winterized)	1
Garage	1-2	Bath, shower	1-6	Windows	2-3
Carport	1	Laundry	1	Heating system	2-3
Maintenance and renovation standard	2-4	Maintenance and renovation standard	2-4	Maintenance and renovation standard	2
Kitchen	*13*	*Other interior*	*4*		
Equipment and decoration	2-11	Fireplace	2		
Maintenance and renovation standard	2	Common room in basement	1-2		

Table AII. Quality index, assessed aspects and points

Appendix 3



Source: Wikipedia, Stockholm

Figure A2.
Map of the Stockholm Municipality