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Driving Forces and Barriers to Improved Energy Performance of Buildings

An Analysis of Energy Performance of Swedish Buildings, 2000–2006

Bente Beckstrøm Fuglseth

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Bente Beckstrøm Fuglseth
bente@byokologi.no

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Abstract

The building sector is responsible for a substantial part of energy use and green house gas emissions in Europe. This report explores driving forces and barriers to improved energy performance of buildings, using the Swedish building sector as a case. The development of energy performance of buildings in Sweden from 2000 until 2006 is explored by applying a threefold understanding of energy performance of buildings: substitution from fossil fuels to renewable energy, conversion from electrical heating to thermal energy and reduction in energy demand.

Three explanatory approaches are used to analyse driving forces and barriers to improved energy performance: the techno-economic approach stresses the physical aspects of infrastructure and technologies, the institutional approach emphasizes the role of institutional factors, while the regulative approach focuses on formal rules and laws. The study concludes that all factors have promoted substitution of fossil fuels with renewable energy, while they have prevented conversion from electrical heating to thermal energy and reduction in energy demand.

Key Words

Sweden, energy performance of buildings, technological change

Orders to:

Fridtjof Nansen Institute
Postboks 326
N-1326 Lysaker, Norway.

Tel: (47) 6711 1900
Fax: (47) 6711 1910
Email: post@fni.no
Internet: www.fni.no

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Polhøgda, June 2008

Bente Beckstrøm Fuglseth

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1 Introduction

The building sector is responsible for a substantial proportion of energy use in Europe. Buildings consume more than 40% of the energy and produce over 40% of the CO_2 emissions, and these figures are rising (European Commission 2007). Hence, buildings have an important role in some of the most important issues of today: global warming and energy supply security. Unless measures are taken, the building sector will keep on contributing to these crises.

However, there exists a wide range of measures that can reduce the energy requirements of buildings and replace fossil fuels by renewable energy. Best-practice examples show that it is even possible to construct new buildings that are net exporters of energy in the course of a year – not that this undermines the need for new innovations for improving energy- and cost-efficiency. The main challenge in the short term is not the lack of sufficient technological solutions, but lack of wide-scale diffusion of existing technologies that can improve the energy performance of buildings.

The diffusion of these technologies is influenced by various factors, like policy instruments, existing energy systems and culture. These factors may differ significantly from one country to another, depending on national contexts. This report inquires into the driving forces and barriers to improved energy performance of buildings, using the Swedish building sector as a case. In a European context Swedish buildings have a heating structure which includes electrical as well as thermal heating systems. This special energy structure makes Sweden an interesting case, as it permits exploration of the co-existence of these two systems and how they affect the possibilities for improving the energy performance of Swedish buildings. Due to the range of heating systems and energy carriers available, energy use in buildings constitutes a complex technological system. Thus the case is not only empirically interesting, but may also be theoretically fruitful, involving the exploration of a complex technological system and the search for factors that influence technological change. The main objective of this report is to open the black box of technological change to explore the various driving forces and barriers to the diffusion of technologies that may improve the energy performance of buildings.

Whereas oil was the main source of heating in 1970, the share of renewables in Sweden has increased continuously since. In addition, the energy used for heating has remained relatively constant from 1970 until today despite an increase in the building stock and living area. A study done by the International Energy Agency (IEA) shows that when adjusting for climate, Swedish space heating is 22% lower than a selection of IAE countries (IEA 2004:50). However, there is still significant energy-efficiency potential in Swedish buildings (Ministry of Sustainable Development 2005).

The IPCC have stressed the importance of reducing greenhouse gas emissions to limit the extent of global warming. Sweden has taken this issue very seriously, as ambitious climate goals exceeding the Kyoto commitments were adopted in 2001 (Ministry of the Environment 2001a). Moreover, these goals have already been fulfilled. This context makes the Swedish case highly topical and interesting to study.

1.1 Research Questions

The objective of this report is to uncover the factors that promote or prevent improved energy performance of buildings in Sweden. The study focuses on the period between 2000 and 2006, as this allows us to contrast the effects of contemporary events with historically founded structures. By focusing on a period near in time, the study also allows the exploration of driving forces and barriers that may still be important. Attention and concern for climate change has increased in recent years, and is one of the factors that will be explored in this report as a possible driving force for improved energy performance of buildings in Sweden.

- *What characterizes the development of energy performance of buildings in Sweden from 2000 to 2006?*

- *Which factors have promoted and which have prevented improved energy performance of buildings in Sweden during this period?*

The report is embedded in an evolutionary economic approach to technological change. Evolutionary economic theory emphasizes the importance of technological systems when exploring technological change. A technological system includes not only the physical components, but also institutions that have a major influence on the selection of technologies (Mulder et al. 1999). Due to the range of available technologies, the technological system of energy performance of buildings is very complex. The system approach to technological change allows us to explore the interdependence of various technologies and institutions and how they affect the energy performance of buildings on an overall level. However, to be able to explain the development of energy performance of buildings, I will have to break the technological system down into subsystems and study the development of these technologies.

To answer the first research question I will use energy statistics to map out the development of energy performance of buildings in Sweden. A threefold understanding of energy performance will be applied, stressing the substitution of fossil fuels with renewable energy, the conversion from electrical heating to thermal energy, and the reduction in energy demand. The characterization of the development of energy performance will also involve changes in diffusion of technologies that may either promote or prevent improved energy performance – like oil, district heating, solar collectors and heat pumps. The spread of these technologies will be used to describe and measure technological change. Some of the technologies are used on a large scale today while others are less widely diffused, and also this diversity can contribute to a fruitful analysis.

The second research question aims at exploring factors that have promoted or prevented the development of energy performance of buildings in Sweden between 2000 and 2006. Three explanatory approaches have been derived from theories of institutions and technological change: the techno-economic, the institutional and the regulative. These approaches will structure the empirical mapping and the analysis of driving forces and barriers. Due to the complexity of the technological system of energy performance of buildings it is impossible to identify all relevant factors. Limiting the study to techno-economic, institutional and regulative factors will permit both broad and in-depth analysis of the influence of these factors on the development of energy performance of buildings.

The *techno-economic approach* has a deterministic view of technological change. The technological regime defines a path or a technological trajectory along which technological changes occur (Mulder et al. 1999). Increasing returns promote the use of technologies that already have been adopted, while preventing further technological change outside the technological trajectory because of the benefits gained by the technologies that have been adopted (Arthur 1989). However, techno-economic factors can also create new trajectories by the introduction of new scientific developments or technological breakthroughs (Cowan and Hulten 1996 in Unruh 2002).

The *institutional approach* stresses the importance of values, norms, cognition and culture for structuring the behaviour of the actors (Scott 2001). If new technologies conflict with the institutional framework, technological change may be slowed down or technologies locked out (Jacobsson and Bergek 2004). Institutional change is a gradual and slow process which tends to lag behind technological change, but it can also be ahead of technological development and act to promote new innovations and diffusion.

The *regulative approach* emphasizes the influence of formal rules and laws on technological change. Policy goals and instruments influence technological change depending on, e.g., type and strength. Economic measures have traditionally been the dominant form of policy instrument in Sweden, but there has also been a long tradition of building regulations. Also the regulative factors may both promote and prevent the use of technologies that affect the development of energy performance.

To be able to go in depth and do a fruitful analysis, I have introduced some limitations. The study will concentrate on heating of buildings (including hot water), and will not include energy used in, e.g., electrical equipment. More than 60% of the energy is used for heating and hot water (Swedish Energy Agency 2006b), so this is an important field to explore. Both new buildings and the existing building stock are included in this study. There exist various measures that can be used for new buildings and the existing building stock. The technological system of energy performance of buildings is complex, with many sub-systems. This study focuses on the most important technologies for each of these building types.

1.2 Outline of Contents

Chapter two presents the analytical framework of the report. It starts by discussing and defining technology and technological change, followed by the operationalization of the concept of energy performance of buildings. Then the three explanatory approaches – techno-economical, institutional and regulative – are presented and operationalized.

Chapter three debates the methodological issues. The research design, the production of data and methodological challenges are discussed.

In chapter four the empirical material is mapped out. Heating systems and technologies are presented first to give a better understanding of the field. The next section presents the development of energy performance of buildings between 2000 and 2006. Also the development of technologies 2000–2006 is discussed. Other empirical findings are presented and organized according to whether they can be characterized as techno-economic, institutional or regulative factors.

The analysis is presented in chapter five. It starts with the characterization of the development of energy performance 2000–2006, and discusses this development in relation to changes at component versus system level. The next part explores the explanatory power of the three approaches on the development of energy performance of buildings. First the explanatory approaches are discussed separately, before I turn to the co-existence and mutual influence of technological, institutional and regulative factors in the last part.

And finally in chapter six, the conclusions of this report.

2 Analytical framework

Improving the energy performance of buildings requires technological change at several levels. Invention and innovation of more energy-efficient and cost-efficient technologies are important. At the same time there are already available a great many technologies that can improve the energy performance of buildings. Diffusion of these technologies is crucial to achieving improved energy performance, both short- and long-term. It is the latter that will be the main focus of this report.

The analytical framework is embedded in evolutionary economic theory. A central concept in this theory is the understanding of technological systems. Technologies are perceived as interlinked to other technologies, users, producers and a range of institutions: these factors together constitute the technological system (Mulder et al. 1999). The system approach to technological change will be central in this report, as energy performance of buildings relies on a range of technologies and institutions. Incorporating institutional factors enables a broader and more fruitful analysis of technological change. According to Rosenkopf and Tushman (1994), it is especially important to explore the role of institutions when studying complex technological systems. Another element in evolutionary economic theory that may be fruitful when exploring the energy performance of buildings is the contextualizing of technological change. Emphasis is put on available technological capability, demand and cost conditions and understandings of what is technologically possible and economically worthwhile to do (Mulder et al. 1999:9). Hence, the techno-economic attributes of technologies must be studied in relation to how these technologies are perceived.

However, previous work on evolutionary theory and technological change has seldom made analytical distinctions between the various factors that affect technological change. By deriving three explanatory approaches, my analytical framework aims at contributing to the theory debate on technological change. The explanatory approaches will also provide a clearer theory foundation for the analysis. Theories of institutions and technological change have been used to develop these approaches. The techno-economic approach stresses the physical aspects of the technologies concerned (Nelson 2003), the institutional approach emphasizes the role of institutional factors, and the regulative approach focuses on formal rules and laws (Scott 2001).

The first part of the chapter will discuss technology and technological change and how technological change can be understood and measured. In the next section I discuss the term ‘energy performance of buildings’ and how it will be interpreted in this study. The next part focuses on the three explanatory approaches that will be used to explain the diffusion of technologies and the development of energy performance of buildings in Sweden: the techno-economic, institutional and regulative approach.

2.1 Technology and Technological Change

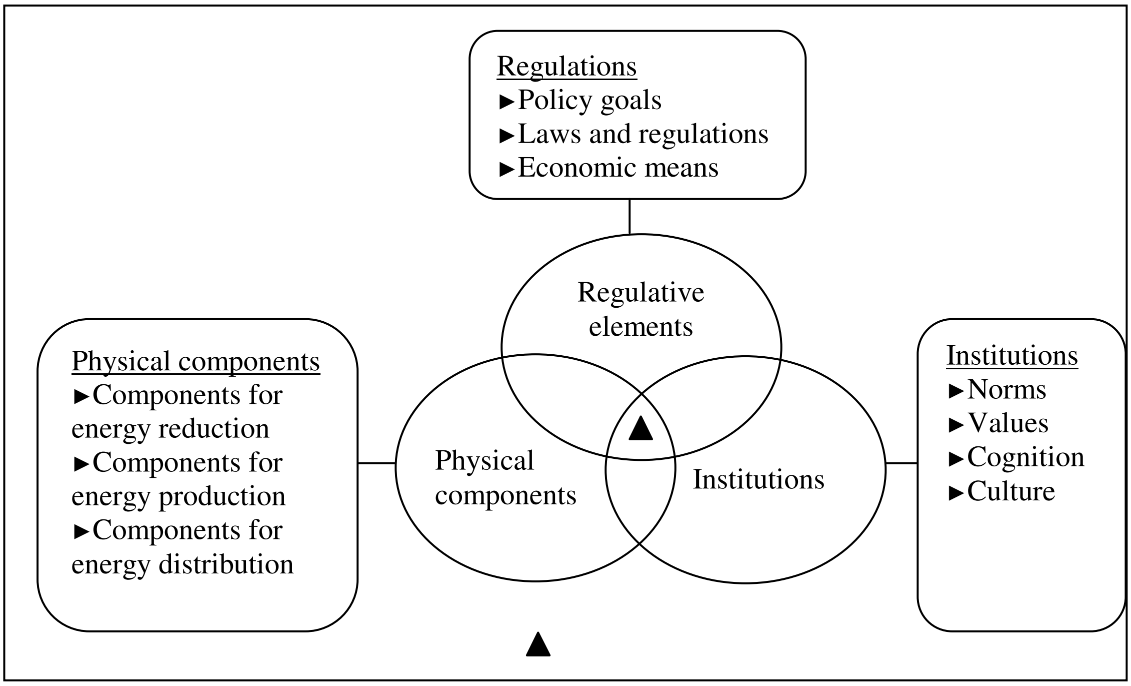
2.1.1 Technology

According to MacKenzie and Wajcman (1985) technology can be understood as consisting of three different layers of meaning: a set of physical objects, human activity, and knowledge. Such a three-layer understanding of technology implies that physical objects like a computer or a heat pump cannot be understood without understanding how they are used, and again the use of the physical objects is linked to knowledge of how to use them, repair, design and make them. According to this understanding of technology, the physical objects in this study will be both active techniques like heat pumps and solar collectors, and passive techniques like architectural solutions and building materials. Various actors – like architects, building engineers, developers and people that buy, rent and own buildings – are the users of the technology. The final layer of technology consists of these actors' knowledge about the technologies.

Technologies that are interconnected can be understood as a technological system (Unruh 2000). This approach can give a better and broader understanding when analysing factors influencing technological change because the focus is not on one particular technology, but on many different technologies related to energy use in buildings. Unruh (2000:819) define a technological system as: '…inter-related components connected in a network or infrastructure that includes physical, social and informational elements.'

In Figure 2.1 the technological system is mapped out as it will be operationalized in this report. Institutions have been divided into the formal institutions; the regulative elements, and the informal elements; values, norms etc., as in the explanatory approaches. The technological system has been broken down into three elements: physical components, institutions, and regulative elements.

Figure 2.1: The technological system of energy performance of buildings



According to Unruh (2000) the concept of technological systems can be understood and analysed at several levels. A technological system consists of many sub-systems, which in turn can be further broken down to new sub-systems. The number of sub-systems, the level of interdependence between these sub-systems and the boundaries of the product will define the complexity of the system (Rosenkopf and Tushman 1994). Hence, the study of a technological system on a higher level leads to increased complexity. The technological system for energy performance of buildings can be described as a complex system due to the range of technologies and sub-systems, the interdependence between heating system and technologies, and the unclear boundaries. The study of a complex technological system allows us to explore the range of interdependent factors that influence the diffusion of technologies.

2.1.2 Technological Change

Technological change can occur at various levels. Jaffe et al. (2002) distinguish three different stages of technological change: invention, innovation and diffusion. Invention is the result of research and is the first development of a new product or process. The innovation occurs when the product or process is put into regular operation, often through applied research and demonstration projects. When the product or process has become standardized and available for mass production and widespread dissemination, the diffusion of technology takes place. It is the latter that will be the main focus in this report. However, inventions and innovations, or the lack of these, will be incorporated in the techno-economic approach as these may be perceived as techno-economic factors that influence the diffusion of technologies.

It is common to distinguish between incremental and radical technological change, and this distinction may also be fruitful in describing technological change in this study. Incremental changes are relatively minor changes of processes or products, and often involve the upgrading of existing products and processes. These changes occur more or less continuously as a result of experience and suggestions from users and engineers. Such changes are of great importance for achieving more effective production etc., but one single incremental innovation will not have dramatic effects (Mulder et al. 1999). While incremental changes can be characterized as continuity, radical innovations represent something completely new, a discontinuity. In the long term they can lead to structural changes, but their impact on society will depend on whether this is a change on the component or the system level (Mulder et al. 1999). It is more difficult to achieve radical changes than incremental changes, but they are necessary for solving some of the environmental problems of today. Existing technology has certain limits, and upgrading will not solve all problems. Hence, radical changes can offer other solutions that would not be possible otherwise.

Unruh's (2002) classification of policy approaches can be fruitful for discussing these issues further, as he classifies them by output and level of change: end-of-pipe, continuity and discontinuity. The end-of-pipe approach requires no change in the system, but treats the emissions. This has been the most common approach: it permits the overall system and infrastructure to remain unchanged, and the focus is instead on the output side of the system (Unruh 2002). These solutions can be effective for minimizing emissions to a specific point. However, despite the decrease in the emissions, this reduction may not compensate for the growth in production and consumption. This report emphasizes substitution of technologies rather than treating the emissions from fossil fuels. Thus, the end-of pipe approach is not relevant in the analysis of this technological system.

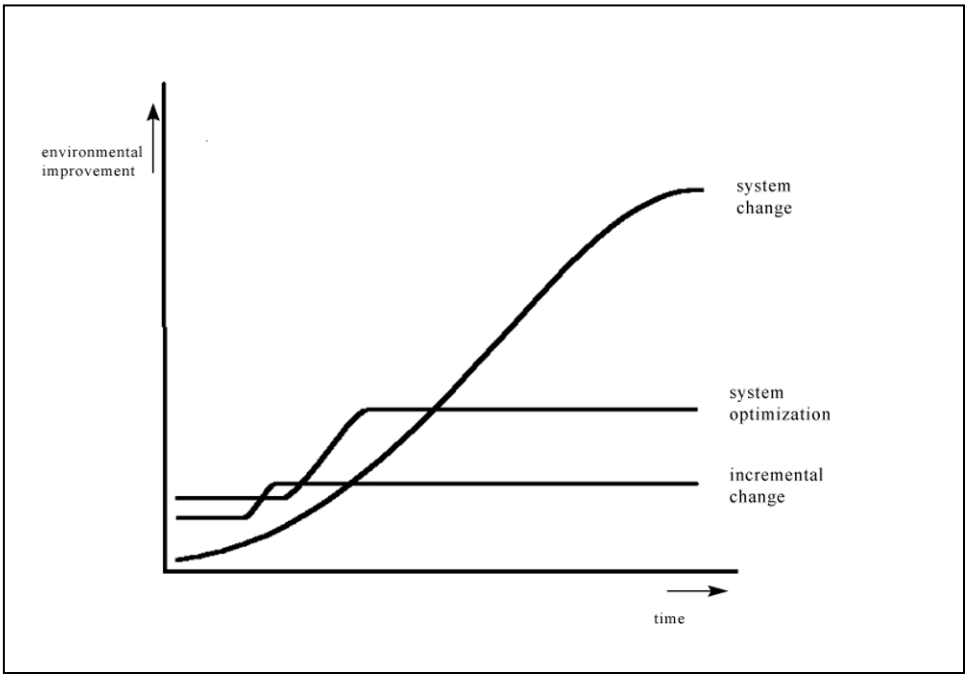
The continuity approach also maintains the system, but selected components or processes are modified. This approach is characterized by incremental innovation or change and tries to maintain as much similarity as possible between the existing system and the new one. As it seeks to limit the apparent differences and create conceptual and physical continuity between the systems, potential users are expected to be more open to the changes (Unruh 2002).

By contrast, the discontinuity approach replaces the system entirely, and represents a radical change. Such solutions require the complete abandonment and replacement of the existing system (Unruh 2002). This approach is most difficult to implement, because it is completely different from the existing situation and such solutions will often be opposed and criticized.

Continuity and discontinuity can be difficult to separate. For instance, it is possible to have discontinuity at the component level and continuity at the system level (Unruh 2002). One example of this can be changing the energy carrier of district heating systems from oil to bio-energy. At the system level, this change can be characterized as continuity, while on the component level it may be perceived as a radical change and discontinuity. Changes at the system level will often be perceived as more fundamental and radical than changes at the component level. Technologies that generate fundamental and radical system-level changes may lead to technological regime shifts (Kemp 1994) or a new technological paradigm (Dosi 1982). Such changes can both affect existing branches in society and give rise to new sectors, requiring changes in organization and in management (Mulder et al. 1999). Technological change at the system level therefore involves physical, social and organizational changes.

Kemp (2002) divides technological options available for achieving a more sustainable development into two separate categories: technology that makes the existing technological regime more sustainable, and technology that represents the development of a new technological regime. While the former involves changes at the component level like end-of-pipe technologies and can be characterized as continuity, the latter demands fundamental changes in the rules and guiding principles of the technological system and represents discontinuity. Figure 2.2 shows technological change at different levels and their effect on environmental improvement.

Figure 2.2: Technological change and environmental improvement



Source: Weterings et al. 1997 in Mulder et al. 1999)

In 2007 the IPCC issued their latest report on climate change which emphasized the increased seriousness of the climate change issue. It stated, with high agreement and backed up by much evidence, that the rise in temperature is due to greenhouse gas emissions from human activity. It is not possible to retrieve the increase in temperature, but a reduction in emissions could stabilize mean temperatures, depending on the peak and decline of the reductions. To ensure that mean temperatures do not increase by more than 2 degrees, the growth in CO_2 emissions must be turned into reduction before 2015, and be reduced by between 50% to 85% by 2050 (IPCC 2007:15). Such radical reduction in CO_2 emissions will require not only incremental changes to optimize the current system, but regime shifts as well. Incremental changes can lead to system optimizing and environmental improvements. But these are limited by the current system and cannot exceed its limits. To increase the environmental improvements further, changes at system level will be necessary. However, these changes occur in a long time-perspective.

2.2 Energy Performance of Buildings

The EU directive on energy performance of buildings define the energy performance of a building as the amount of energy that is actually consumed or estimated to meet the various needs of standardized use of a building. The calculation of the energy performance of a building is to include factors like heating and air conditioning installations, the application of renewable energy resources and the design of the building (Directive 2002/91/EC 2002).

Energy efficiency can be understood as the energy used (input) will yield greater amounts of useful work (output) or that less energy is needed to perform the same function (National Board of Housing, Building and Planning 2005). Reduction in energy demand is the most important measure that can be taken to improve the energy performance of a building, as the most sustainable type of energy is simply energy that is not used (Næss 1997). The demand for energy can be reduced by energy-efficiency measures or by the exploitation of passive solar energy. Energy-efficiency measures in a building can reduce heat loss by better insulation, energy-efficient windows, materials and construction that reduce thermal bridges (Energirådgivningen 2006, Energirådgiverna 2007a, Energirådgiverna 2007b, Swedish Construction Federation 2007, Boligministeriet 1998). Heat loss can also be reduced by an optimal choice of building type, localization (local climate) and the grouping of buildings. The two latter are also important in exploiting passive solar energy (Næss 1997). Passive solar energy can in addition be exploited by optimal placing of windows and rooms that may reduce the need for heating and cooling (Boligministeriet 1998). I will concentrate on building techniques; choices regarding localization and grouping of buildings are beyond the scope of this report.

The term exergy efficiency focuses on the correlation between energy forms and the purpose. Electricity is high-quality energy and can be used for both heating and machinery, while thermal energy from for instance bio-energy can serve one purpose only: heating. Exergy efficiency can be reached when the energy quality of the source is in correlation with the demand. This implies that high-quality energy like electricity should be used for high-quality purposes and low-quality energy like thermal energy should be used for low-quality purposes (Næss 1997). Even if the energy comes from a renewable energy resource like hydropower, it is not ‘efficient’ if it is used for heating. Reducing the use of electricity for low-quality purposes may lead to less need for electricity from fossil fuels.

The substitution from fossil fuels to renewable energy is important for reducing greenhouse gas emissions from the building sector. A wide range of renewable energy technologies are available today, among them solar collectors, bio-energy and heat pumps.

Conversion from electrical heating to thermal energy is not mentioned in the definition of energy performance of buildings in the EU directive. However, I will include this element in my understanding of energy performance as it is important for increased exergy efficiency. Hence, energy performance of buildings covers three different aspects of energy use in buildings: substitution from fossil fuels to renewable energy, switching from electrical heating to thermal energy, and reduction in energy demand. These three elements are all of great importance for reducing climate gas emissions from the building sector and for increasing energy-supply security. Table 2.1 presents the technologies in this study and how they may contribute to improved energy performance of buildings. They are categorized by feasibility for improving the energy performance in existing buildings and new buildings.

Table 2.1: Technologies that may improve the energy performance of buildings

	Substitution of fossil fuels with renewable energy	**Conversion from electrical heating to thermal energy**	**Reduction in energy demand**
New buildings	►solar collectors ►bio-energy ►heat pumps	►bio-energy ►heat pumps ►solar collectors ►district heating	►energy-efficient windows ►increase insulation ►construction/design for exploiting passive solar energy and reduce thermal bridges
Existing buildings	►solar cells ►bio-energy ►heat pumps	►bio-energy ►heat pumps ►solar collectors ►district heating	►energy-efficient windows ►increase insulation

Energy performance will be understood as a result of inherent attributes of the building, like the current heating system, energy technologies and building techniques. Two buildings with the same energy performance may have differences in energy use due to the behaviour of the people living there. As the focus in this report is on technological change, and the technological system is complex in itself, people's behaviour will not be included as a factor in this report. Energy statistics provide data on the energy delivered to buildings: this means the amount of energy bought by the consumers. This makes it impossible to measure the development of the energy demand on an aggregate level. Instead, I will use statistics for delivered energy as a measure, even though this is not completely accurate.

2.3 Three Explanatory Approaches

This section presents the explanatory approaches that will be used to explore the second research question: the factors that have promoted and prevented the improvement of energy performance of Swedish buildings from 2000 to 2006. The three approaches are derived from the claims of theories of institutions and technological change. Several of the central terms in these theories, like technological trajectories, path dependency, selection environment and increasing returns, include all the factors – techno-economic, institutional and regulative. However, these concepts are cultivated and linked to one of the approaches to give a clearer distinction between them. Thus, the approaches do not exclude but rather supplement each other, providing a broad basis for the analysis. While the techno-economic approach focuses on how qualities of the technologies spur technological change, the institutional approach emphasizes how institutional factors like norms and culture affect the spread of technologies, and the regulative approach stresses how policy instruments like regulations and economic measures affect technological change.

2.3.1 The Techno-economic Approach

The power to affect change is imputed to the physical technological components themselves. This is one of the claims of technological determinism (Marx and Smith 1994). Hence, technology develops as the sole result of an internal dynamic and society adapts to the changes. Technological determinism is the most influential theory of the relationship between technology and society, according to MacKenzie and Wajcman (1985). It is often held that technologists follow the logic of scientific discoveries and introduce new techniques and products into society. However, scientific development is seen as being unaffected by society, with the technologists simply ‘applying science’ (MacKenzie and Wajcman 1985). Another dimension of technological determinism is that technological change causes social change. The introduction of new technologies offers new opportunities which lead us to change our ideas and lifestyles.

The importance of scientific knowledge for technological change is discussed further by the ‘technology-push’ hypothesis, where technological change is understood as the result of human ingenuity or new scientific knowledge (Christiansen 2001). The speed and direction of technological knowledge may create important conditions for the development or improvement of products (Ende and Dolfsma 2002). ‘Technology push’ is most often used to explain inventions and innovations. But as improvements in existing technologies, whether making them more cost-efficient or more user-friendly, may be of great importance for the diffusion of these technologies, this hypothesis may also offer an explanation for the development of energy performance of buildings.

The concept of technological trajectories explores the claims of technological determinism further as it provides explanation for the internal dynamics of the technologies. According to Mulder et al. (1999) technological trajectories can be perceived as expressions of a technological regime which defines a certain path. Technological change will occur along this path under the influence of the current regime. Existing components, theories and methods will influence the further development of the technology (Kemp 2002). This implies that both institutional and techno-economic factors are integrated in the concept of technological trajectories. However, I will concentrate the understanding of technological trajectories on techno-economic factors, while the institutional factors will be integrated in path dependency, to be discussed as a part of the institutional approach. Techno-economic factors will be understood as attributes inherent in the technology or the technological system that affect the possibilities for diffusion.

According to Kemp (1994) a major reason why technological change occurs along a technological trajectory is that already diffused technologies and designs have benefited from evolutionary improvements in terms of costs reduction and better performance. He stresses the importance of the *selection environment* for explaining the mechanisms behind the selection of a technology, and emphasis is put on the historical context. The increased attractiveness of adopted technologies is by Arthur (1988) referred to as *'increasing returns to adoption'*, a term we shall use in this report. He identifies several sources that may cause these benefits, two of which may be relevant for exploring the influence of techno-economic factors on the development of energy performance of buildings. *Learning by using* is a result of the learning affects that come from a technology, once it has been adopted. The more a technology is used, the more is learned about it, and it may be improved and developed further. Falling costs per unit as production increases lead to *economies of scale in production* and cheaper components. Increasing returns to adoption affects the selection environment and gives benefits to already adopted technologies in the form of beneficial capital outlays and physical infrastructure. According to Freeman (1991) it is the economic elements of the selection environment that are the most important for the spread of technologies. The selection environment also creates technological lock-in, which makes any technological change outside the technological trajectory difficult.

Overcoming technological lock-in may be crucial for the diffusion of technologies that are hampered by existing technological trajectories. However, overcoming lock-in has been little explored: lock-in has simply been seen as an exogenous force driven by extraordinary events or crises. Cowan and Hulten (1996, in Unruh 2002) have explored this issue further and have identified six extraordinary events that may overcome lock-in. Four of these are related to technology: crises in the technology evolved, technological breakthrough, niche markets, and new scientific results. The exogenous forces must be stronger than the increasing returns to adoption discussed above for the lock-in to be overcome. And most likely, they must be followed by changes in institutions and regulations.

To evaluate the techno-economic approach I will examine relevant techno-economic factors and discuss *if* and *how* they have influenced the diffusion of technologies and the development of energy performance of buildings. For the techno-economic approach to have explanatory power, the techno-economic factors must be shown to have affected the development of energy performance. The existing physical infrastructure influences diffusion in various ways depending on the attributes of the specific technologies: what is an advantage for one technology may be a disadvantage for another. If there has been technological change that indicates regime shifts, have exogenous technological factors been important for overcoming lock-in? The presence of one or more of the events identified by Cowan and Hulten (1996 in Unruh 2002) may indicate the development of a new technological trajectory. In the following, I examine three techno-economic factors: physical infrastructure, attributes of the technologies, and prices and costs. In what way have these affected the diffusion of technologies, and how has this affected the energy performance of buildings? To answer this I will rely on interviews, previous studies and characteristics of the technologies.

2.3.2 The Institutional Approach

Technological determinism has been criticized by advocates of social construction of technology for ignoring the influence of institutions on the development of science and technology. Scientists and technologists are members of society and their activities cannot be separated from their lives within society. Studies have revealed that institutions affect science and technology in several ways. Also the second aspect of technological determinism – that technological change causes social change – has been criticized. It is not the new technologies that cause social change, but the way we choose to implement and adopt them. Simply inventing or introducing new technologies is not sufficient for them to be used: institutions have a major part in deciding which technologies are adopted and which are not. The social construction of technology stresses the importance of institutions and how technological change and institutional change are interlinked. This implies that similar technologies can have different effects in different situations (MacKenzie and Wajcman 1985).

As the ‘technology-push’ hypothesis can be related to technological determinism, the ‘demand-pull’ hypothesis may be connected to the social construction of technology. This hypothesis assumes that technological change is triggered by social needs (Christiansen 2001). The rise of a market for specific technologies may lead to the innovation and diffusion of these technologies.

The claims of social construction of technology are followed by several scholars who stress that the diffusion of technologies depends on technological factors only to a minor extent (Rohracher 2002, Unruh 2002). The lack of sufficient institutional change represents a far greater limitation for technological change. Over time, technological systems become integrated with society through the adaptation of specific preferences, expectations and routines (Unruh 2002). Jacobsson and Bergek (2004) emphasize the importance of the institutional framework for new technologies to gain ground. If the new technologies and the institutional framework are conflicting, several functions may be blocked. Successful technological change is therefore strongly related to institutional change. For understanding institutions, the definition offered by Scott (1995) may be useful:

> Institutions consist of cognitive, normative, and regulative structures and activities that provide stability and meaning to social behaviour. Institutions are transported by various carriers – cultures, structures and routines – and they operate at multiple levels of jurisdiction (Scott 1995:33)

Institutions may be formal or informal (Foxon 2002). Informal institutions involve the normative and cognitive elements, while regulative structures can be characterized as formal institutions. I distinguish between formal and informal institutions in the analysis, and the latter will be discussed later as a part of the regulative approach. The term 'institutions' will from now on be understood to refer to *informal* institutions.

The normative system includes both values and norms. While values represent the preferred and desirable, norms specify how things should be done, and indicate what are seen as legitimate ways of reaching the goals. The cognitive stresses the importance of external cultural frameworks for shaping subjective beliefs: '...the shared conceptions that constitute the nature of social reality and the frames through which meaning is made' (Scott 2001:57). Thus, the cognitive encompasses what we normally take for granted, like roles and routines (Scott 2001).

Unruh (2000) stresses the importance of path-dependent increasing returns to scale. Path dependency can be understood as a self-reinforcing sequence of events. Out of at least two possibilities, one technology is chosen, and this event triggers a move towards a particular path. Positive feedback mechanisms then reinforce the movement along this specific path (Deeg 2001). According to Liebowitz and Margolis (1995), a path dependency emerges when alternative technologies are available and would be more efficient in the long term than the technology chosen. But once a technology is chosen, it becomes locked into this path '...as all the relevant actors adjust their strategies to accommodate the prevailing pattern.' (Thelen 1999:385) Hence, path dependency and technological trajectories are interlinked and may reinforce each other. However, it is the institutional factors that drive path dependency, not techno-economic factors in the understanding of technological trajectories used in this report.

The influence of increasing return to adoption and selection environment can also be applied to the relationship between institutional factors and diffusion of technologies. Institutional factors like norms, supply-users linkages and people's preferences and beliefs also constitute the selection environment. These factors affect the perception of technologies and the mechanisms influencing the selection of the technologies. *Informational increasing returns* are one of the sources of increasing returns to adoption identified by Arthur (1988). Once a technology has been adopted, it becomes more known and better understood. The use of widespread technologies is perceived as more safe, so they become even more attractive.

The selection of technologies has been discussed at length in studies of competing technologies which reveal that choices among and between possible technologies are not obvious. Rosenkopf and Tushman (1994) found that the dominant technological outcomes were not determined by the technical aspect of the technology in question, but were socially constructed and determined by organizational coalitions. Rosenkopf and Tushman (1994) distinguish between simple and complex technologies. For simple technologies, the choices between competing designs are based on measures like price and performance, and the influence of socioeconomic factors will be minimal. For more complex technologies, there exist several alternative ways of measuring the performance of the technology concerned. Social, political and organizational factors are of importance since more organizations are involved in the evolution of complex technologies. According to Rosenkopf and Tushman (1994) technological change is influenced by both technological determinism and social construction of technology. However, the social construction of technology occurs before the emergence of a dominant technology, while technological determinism after the dominant technology has been established.

However, institutional changes are characterized by inertia and will often not follow the invention and innovation of technology. Continuity is integrated in institutions: discontinuity and change mean deviation from the established, and require new routines and a new agenda (Lerstang and Mydske 2005). Changing an institution is a gradual and slow process that occurs when '... a sufficient number of influential members of society recognize or become convinced that continued expansion of a technological system is no longer tolerable' (Unruh 2002:322). Changes in taste are one of the extraordinary events identified by Cowan and Hulten (1996 in Unruh 2002) that may overcome lock-in. Although this may not be sufficient for change to happen, it can be a necessary condition according to Unruh (2002).

In order to assess the institutional approach I will examine institutional factors and discuss *if* and *how* they have affected the diffusion of technologies and the development of energy performance of buildings. For the institutional approach to have explanatory power, the institutional factors must be shown to have influenced the diffusion of technologies. The institutional factors will be explored through the influence of the cultural contexts that shape subjective meaning and interpretation of objects (Scott 2001). Three institutional factors will be explored: the Swedish cultural context, the perception of technologies, and supplier–demander linkages. I will rely on previous studies, policy documents and interviews with relevant actors.

2.3.3 The Regulative Approach

The regulative approach also stresses the influence of society on technological change, and can therefore be seen as a part of the social construction of society tradition. However, it is the formal rules and laws which constitute this approach. The regulative approach includes setting the rules: monitoring conformity to them and sanctioning activities to manipulate future behaviour through rewards and punishment (Scott 2001). By using a set of techniques and policy instruments, the government aims at effecting social change. Vedung (1998) argues for using a threefold typology of policy instruments: regulations, economic measures and information, which represent the stick, the carrot and the sermon. He claims that all policy instruments can be reduced to these three. In this study, I limit the regulative approach to only the first two: regulations and economic measures.

The purpose of regulations is to mandate specific behavioural changes or technological choices. This approach is commonly classified as either technology-based or performance-based. An example of the former is technology standards that require the use of specific products, processes or procedures, such as standards like 'best available technology' (BAT). The latter involves specifying a certain quantitative pollution limit, but does not necessitate using any specific technology. The rationale for using such policy instruments is the belief that regulation and ambitious standards can lead to the adoption of new technologies, as well as increased private investment in research that can lead to new inventions (Christiansen 2001).

Critics claim that using regulations and setting standards will not lead to cost efficiency because it is difficult to set standards that will prove optimal for all. Moreover, if standards are set, there will be no incentives to develop technology that moves beyond the current standards. Christiansen (2001) claims that in such cases standards will be 'technology freezing' rather than 'technology forcing'. This problem can be eased through additional policy instruments like financial support to research. However, how strict the regulations are will be important for technological change. Standards can also create technological lock-in, making it difficult to upgrade the standards through technological change.

Kemp (2000) claims that for there to be radical technological change, it is necessary to have stringent regulations like product bans. Regulations have not as much to offer innovation as the diffusion of technology. For widespread diffusion, regulation will be necessary according to Kemp (2000), whereas for promoting innovations, a better approach can be the threat of regulations than actual regulations. Jaffe et al. (2002) on the other hand refer to several studies that conclude that economic instruments provide greater incentives for adopting new technologies than regulations. However, this disagreement implies that the effect of the policy instruments is likely to change according to the context and the level at which they are set.

The current trend in Europe is for policy instruments to move from regulations towards economic incentives. Instead of having equal standards, the focus of policy is on economic measures (Christiansen 2001). While regulations are mandatory and command a specific behaviour, economic measures like tradable permits, taxes and subsidies create economical incentives for such behaviour. This approach is based on market economics with confidence in the market mechanism as a regulatory force. But externalities make it necessary to intervene in the market and regulate prices to avoid these externalities. Taxes and subsidies are intended to correct the market price to a level that will result in an optimal level of externalities, as well as ensuring cost efficiency. Firms and individuals will adapt to the new price by reconsidering their choices and opting for new, cost-efficient technologies.

Economic measures provide incentives for firms and individuals to take actions that will reduce pollution because it is in their own interest. At the same time these actions collectively meet policy goals. Economic measures may offer incentives to technological change because the actors will try to develop new technologies in order to avoid taxes. In contrast to regulations, such policy instruments also provide incentives for moving beyond the current environmental standards (Christiansen 2001). Taxes can be used both to punish undesirable behaviour (like emission taxes) and to reward desired behaviour (like tax relief). Subsidies can be both for investment and for research and development (R&D) (Wang 2004). By altering prices in favour of certain products or technologies, these policy instruments aim to promote environmentally-friendly solutions (Christiansen 2001).

Policy instruments can lead to lock-in, as they may favour some technologies and exclude others. At the same time policy instruments aimed at promoting technological change today may become obstacles to technological change in the future. Change in policy instruments may therefore be a necessary condition for overcoming lock-in, and is one of the exogenous forces discussed by Cowan and Hulten (1996 in Unruh 2002).

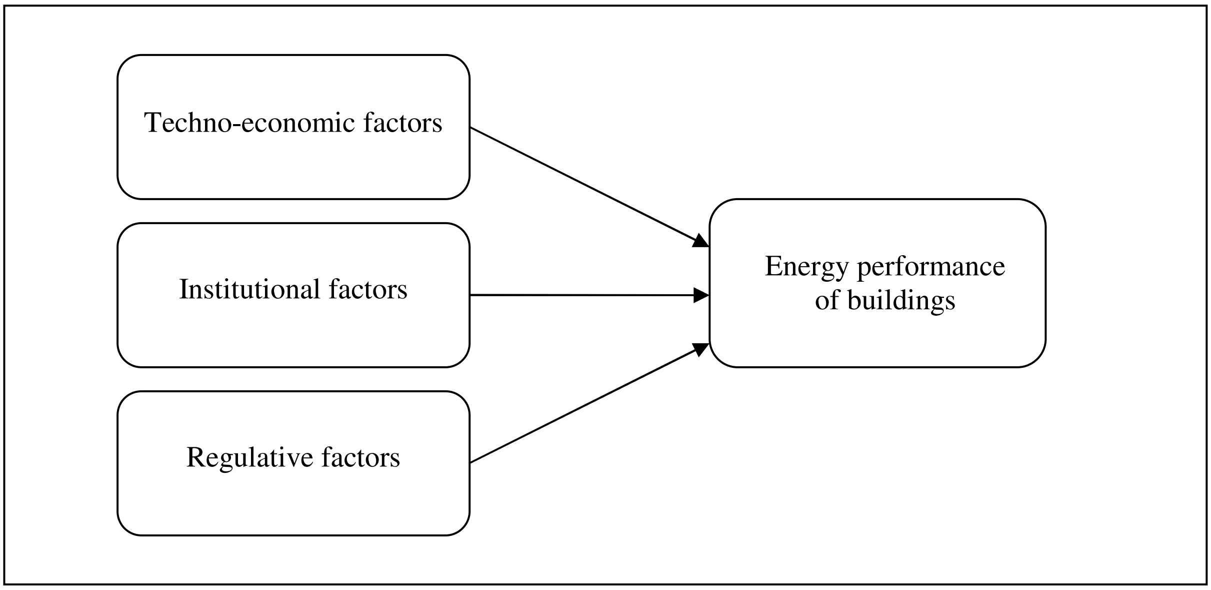
To assess the regulative approach I will identify relevant regulative factors and discuss *if* and *how* they have affected the diffusion of technologies and the development of energy performance of buildings. Three regulative factors will be explored: policy goals, regulations, and economic measures. To determine the explanatory power of the regulative approach, I will have to show a connection between the regulative factors and diffusion of technologies. For this, I will rely on statistics on the development of the technologies. However, this may not be sufficient for strengthening the regulative approach. Interviews will be important, as the actors involved in the various technologies may offer information and explanations not apparent in statistics.

2.4 Summary of the Analytical Framework

Figure 2.3 maps out the explanatory model for the development of energy performance of buildings. However, before applying the explanatory approaches, we must determine how the technologies affect energy performance. The diffusion of technologies will be analysed and categorized according to how it affects the energy performance of buildings and whether it requires changes at the component or the system level. This also allows us to explore the possibilities for improving energy performance by system optimization and by regime shifts.

The rest of the analysis will be structured around the explanatory approaches. The techno-economic, institutional and regulative factors co-exist and have a mutual influence on the development of energy performance of buildings. By separating and cultivating the factors, the analysis will provide a clearer, more structured exploration of the driving forces and barriers to improved energy performance. However, the co-existence and mutual influence of the techno-economic, institutional and regulative factors will also be discussed.

Figure 2.3: Explanatory model of the development of energy performance of buildings



3 Methodology

3.1 Case Study Research

Yin (2003) stresses the importance of the research questions posed in deciding what methodology to use. When the research questions are *how* and *why* and the focus is on contemporary events, case studies may be the preferred methodology. The research questions of this report require a methodology that can allow me to go in depth and study energy use in buildings in relation to several factors. The objective is to analyse *how* the energy performance of buildings has developed between 2000 and 2006 and *why* it has developed in this way. A quantitative methodology can be used to reveal technological change and how the development of energy performance has been in the years under study. However, it is not the best methodology when the aim is to explore the factors that have promoted or prevented improved energy performance of Swedish buildings. This requires a methodology that allows us to study and understand complex phenomena.

One central element in the case-study research design is data triangulation. Employing multiple sources of evidence, documents, interviews and observations, and a mix of quantitative and qualitative data, will increase the validity and reliability of the study. This is important for this report as I need both to use statistics, interviews, previous studies and policy documents in order to answer the research questions.

According to Yin (2003) a case study is especially appropriate when studying contextual conditions '...where the boundaries between phenomenon and context are not clearly evident...' (Yin 2003:13). This is also the case in the field of energy use in buildings in Sweden. It is not possible to understand and explain the development of energy performance here without including this context as an important factor. Therefore, the case-study approach would appear to be an appropriate methodology for this study.

3.2 Research Design

The objective of this report is both to study how the energy performance of Swedish buildings developed from 2000 to 2006 and to explore the driving forces and barriers to improved energy performance. The use of statistics on energy use and sale of components is necessary to conclude how energy performance has developed. However, these statistics can help to answer how the energy performance of buildings has developed – but not why. To answer the second research question, I have interviewed a range of actors involved in the technologies in focus, or in energy use in buildings in general. These interviews in combination with document studies are used to analyse how techno-economic, institutional and regulative factors promote and prevent improved energy performance of buildings.

By studying techno-economic, institutional and regulative factors on the three elements of energy performance of buildings, this study aims at exploring a range of complex issues. This involves some methodological challenges in doing a fruitful and in-depth analysis. By choosing only one of the sub-systems, for instance building techniques or bio-energy, I could go into greater depth and study the system more thoroughly. However, in limiting the study to one of the sub-systems, I would lose the possibility to study the relationship between the various sub-systems and how they influence the development of energy performance. Such a limitation would also make it impossible to study the relationship between the several elements of energy performance of buildings, like substitution from fossil fuels to renewable energy, the conversion from electrical heating to thermal energy and the reduction of energy demand. Focusing on the overall system of technologies enables me to study the relationship between the technologies and the various elements of energy performance. However, the objective of this report is not to uncover causal relationship, but explore driving forces and barriers.

For each of these energy carriers I have gathered information about institutional, technological and regulative factors that promote and prevent the use of these technologies. Although studying the technological system, I have to break it down into sub-systems and analyse the development on sub-system level first. Then I can discuss the development on the sub-system level in relation to the other sub-systems, the overall system and improved energy performance of buildings. However, as several different sub-systems are included in this analysis, I need to place some limitations on how to study these technologies, to prevent the study from becoming too large and cumbersome. Since the objective is to explain the development of energy performance of buildings, the aim must be to get an overview of these sub-systems and factors relevant for the technological system. In the course of data collection, I several times looked back and re-considered the research questions and analytical framework, to be sure of not losing focus. As noted by Yin (2003), one of the pitfalls of this kind of case study is that the researcher may end up focusing solely on the sub-units, failing return to the larger unit of analysis.

3.3 Production of Data

3.3.1 Interviews

I interviewed various actors involved in the field of energy use in buildings, like interest groups promoting the technology, actors working in governmental authorities and actors involved in R&D and construction of buildings. (See Appendix 1 for a complete list of informants.) By studying relevant reports, studies and internet pages I got an overview of the field and relevant institutions and organizations. The informants were identified by searching the Internet pages of the relevant organizations. In total, 9 interviews were conducted, in Norwegian and in Swedish, during the period from 23 October to 17 November 2007. Having read through a large selection of documents in Swedish, I knew the most important terms which differed in the two languages, and could use the Swedish term when necessary.

I have chosen to provide anonymity by not referring to the informants by name in the text, although they are listed in Appendix 1. The reason for anonymity is twofold. Letting the informants know that they will be anonymous can contribute their speaking more openly during the interviews. In addition they are not expressing themselves on behalf of their organizations, but can reflect more freely on the issues discussed during the interview. As one of the objectives of this report is to reveal informal institutional factors like values and norms, this aspect is important. However, there are also some implications for the reliability of the report, and this is discussed in greater detail later.

3.3.2 Statistics

Swedish energy statistics have been an important source of information for mapping the development of energy performance of buildings from 2000 to 2006. When using statistics it is important to clarify which measurements have been used. For measuring the substitution of fossil fuels by renewable energy, I have calculated the share of renewables and of fossil fuels in district heating and electricity production, and summarized this with the other renewable and fossil energy carriers. (See Appendix 3 for calculations.) The conversion from electrical heating to thermal energy has been measured in terms of changes in the share of electrical heating out of total energy use. As noted earlier, is it not possible to measure energy demand on an aggregate level, so I have chosen to use statistics on energy delivered instead. (See Appendices 4 and 5.)

The main focus is not changes in absolute figures, but as shares of total energy used for heating. Thus, there may be a decrease in bio-energy on aggregate level, but when seen as a share of total energy used for heating, there can have been a small increase. This is due to the decrease in total energy used for heating. As the focus of this report is on the *substitution*, *conversion* and *reduction* of energy, this will give a better understanding.

3.3.3 Document Studies

I have studied relevant reports and previous studies. Such documentation has been important for providing an overall view of the field when defining the research questions, and later as an important source of data for outlining the development of the energy performance of buildings. The use of documents and of interviews in this study have complemented each other, and have been used for data triangulation to ensure validity.

3.4 Reliability, Validity and Generalization

One of the main challenges when conducting a case study concerns reliability. If another researcher is doing a similar study and following the same procedures, she or he should ideally also arrive at the same findings and conclusions. According to Yin (2003), one way of ensuring reliability is to detail how the study has been conducted and document all procedures. By explaining the report research design and the production of data, I have tried to ensure the reliability of the report. However, by protecting personal integrity and not making the transcribed interviews available to other researchers or revealing the names of interviewees, reliability is weakened. But I consider the confidentiality of my informants and the possibility for thereby obtaining better data as more important.

Validity concerns whether the researcher really measures what he or she intends to measure. The operationalizations of the research questions are important for collecting the data and for ensuring that the data are the best for measuring the types of changes that are studied. This has been integrated in my analytical framework. Another important issue is whether the data themselves are reliable. This can be improved by using multiple sources of evidence and by double-checking information (Yin 2003). One weakness of the validity of this study is that there is no accurate measure of energy demand on the aggregate level. However, instead of changing the operationalization of energy performance, I have chosen to use the most appropriate data available: statistics on energy delivered.

One criticism against case studies is that it is not possible to generalize from a single case, so case studies cannot contribute to scientific development (Flyvbjerg 2004). However, there are various different forms of generalization which can be used under different circumstances. Generalization is often thought of as *statistical* generalization, known from natural sciences and quantitative methods. By using a random sample of units, the conclusions of a study can be generalized to units that were not a part of the original study. With case studies, we should bear in mind that they are not generalizable to populations, but to theory. By using previously developed theory as a template and comparing it with the empirical results of the case study, the researcher may undertake an *analytical* generalization (Yin 2003). According to Kvale (1997), analytical generalization is a contemplated evaluation of the degree to which the findings of a study may be used as guidelines for what can happen in a similar situation. The claims of generalization are based on a specification of the evidence, and the arguments must be explicit. The purpose of analytical generalization is to test existing theory and assess whether the theory can explain the empirical findings. If the findings confirm the theory, then it will be strengthened. If, however, the findings deviate from the theory, then the researcher can offer propositions for further theory development (Yin 2003).

4 Empirical Mapping

This chapter maps out the empirical material which will be used as a basis for the analyses of the next chapters. First I discuss the various heating systems and the energy technologies explored in this study. The next section presents the development of energy performance of buildings in Sweden 2000–2006, using the threefold understanding of energy performance presented in chapter two. The next three parts explore the empirical findings and relate them to techno-economic, institutional and regulative factors.

4.1 Heating Systems

Two different heating systems are used in existing buildings in Sweden: the waterborne heating system and direct electrical heating. The former type is clearly the most common heating system in Sweden today. In a waterborne heating system, hot water is distributed around the building through radiators, or water pipes in the floor. A range of energy technologies may be used for heating the water: electrical boilers, heat pumps, solar collectors and oil boilers. The advantage of this heating system is its flexibility, due to the possibilities for substituting technologies.

In a direct electrical heating system, electricity is converted into heat using panel heaters or electrical floor heating. The use of the latter is growing rapidly (20–30% per year). However, most of the electrical floor heating is installed for reasons of comfort, and is applied in addition to other heating technologies (National Board of Housing, Building and Planning 2003b:36). Air-to-air heat pumps are also classified as direct electrical heating in Swedish energy statistics. Such air-to-air heat pumps cannot cover the entire heating demand of a building, and additional energy is needed. At the same time the heat energy is not distributed through a waterborne heating system, but directly into the room (Swedish Energy Agency and SCB 2007b: 34). The use of direct electrical heating is very low in multi-family structures (2%), higher in non-residential buildings (15%) and most in one- and two-family houses (19%) (National Board of Housing, Building and Planning 2003b:10).

During the 1990s the passive house concept was introduced by the Passivhaus Institut in Germany. Due to the employment of special building techniques, passive houses will not need either of the heating systems discussed above. Such houses are constructed according to specific principles for reducing the demand for energy, through measures like special windows, thicker insulation, extracting passive solar energy and minimizing thermal bridges. These measures reduce the need for delivered energy to a minimum. The requirement for classification as a ‘passive house’ is that the energy demand for heating shall not exceed 15 kWh/m^2/year. Because of the air-tightness, a ventilation system is required. Heat from the exhausted air is recovered using an air-to-air heat exchanger, which will be sufficient to heat the building (Passiv Haus Institut 2006).

4.2 Energy Technologies

Various renewable energy resources can be used for heating of buildings: solar energy, water, biomass and surrounding energy. The energy from some of these resources must be transformed into other forms of energy in order to be useful. Energy carriers such as electricity, pellets or hot water may be used to transport the energy to the end-user. Solar energy can be converted to energy carriers like electricity and thermal energy, and biomass to, e.g., pellets (Energifakta 2008). This section will focus on energy technologies that transform energy into thermal energy that can be used in waterborne heating systems.

4.2.1 Solar Collectors

Solar collectors transform solar radiation into thermal energy and transfer the heat to a medium, often water. Solar collectors are connected to a storage tank and a distribution system, and may provide heat energy for hot water and heating (Boligministeriet 1998). Compared to solar cells, solar collectors have the advantage of making use of diffused radiation, not just direct radiation as in the case of solar cells. They are effective also on cloudy days and have higher energy-conversion efficiency than solar cells. However, solar collectors produce most energy during the summer, when the need for heating is lowest. In Sweden, solar collectors have to be supplemented with other energy carriers during the winter (Energy Markets Inspectorate 2007).

4.2.2 Bio-energy

Bio-energy is energy extracted from biomass. There are several sub-groups of bio-energy and for heating of buildings: wood fuels are the most common, but also oil or gas produced from biomass may be used. Bio-energy for heating can be separated between central heating and point heating. Central heating systems require a pellets boiler and waterborne heating systems, while point heating may involve stand-alone stoves that provide space heating for a room (Nobio 2008). Pellets have several advantages compared to firewood: they deliver more energy per volume unit, can be easily transported and stored, and can also be used in automatic boilers (Skagestad 2005). Statistics do not distinguish among the various forms of bio-energy or point and central heating, so all these will be included in the figures for use of bio-energy. In addition, bio-energy is used in district heating systems.

4.2.3 Heat Pumps

Heat pumps extract the heat from the surroundings (air, water or ground), and transfer it via a fluid to the building. However, electricity is needed to transport the heat and drive the heat pump. For 1 kW input, approximately 3 kW of heat output is gained, depending on local conditions and the type of heat pump (Nowacki 2006). Various kinds of heat pumps are available on the market: air-to-air, air-to-water, exhaust air-to-water and ground/water/rock- to-water. Except for the air-to-air heat pumps, these require a waterborne heating system. Most heat pumps cannot cover the entire heating demand of a building and additional energy is needed, but the degree of energy supply differs from one type to another. In fact, the most expensive rock-heat pumps can cover the entire heating demand of a building (interview PR).

4.2.4 District Heating Systems

In district heating systems, energy production is moved from the building to a central plant where thermal energy is produced by the combustion of e.g. biomass or waste materials. Hot water is transported from this plant to buildings through a system of well-insulated pipes, and then distributed around the building by a waterborne heating system (Swedish District Heating Association 2008). Buildings connected to district heating systems may get their entire heating demand covered by this energy. Due to the high costs of the district heating net, it is most cost-efficient to connect buildings located close to the central plant or the existing net. Having many buildings connected at the same time and in the same area is also important for reducing costs (Persson and Sernhed 2004).

The energy input in district heating systems has changed over the years, with the fossil share decreasing and the renewable share increasing. Between 2000 and 2006, the fossil share was reduced from 18 to 16%, while the renewable share increased from 74 to 79% of energy input (Swedish Energy Agency 2007b: 24–25).

4.2.5 Waterborne Electrical Heating

Electricity can be used for heating in two different ways: direct electrical heating as discussed above, and waterborne electrical heating. The latter uses electrical boilers to heat water that is distributed in a waterborne heating system. Air/exhaust air-to-water heat pumps are classified as waterborne electrical heating in energy statistics, as the energy is distributed in a waterborne heating system. Such a system cannot cover the heating demand of a building alone. (Swedish Energy Agency and SCB 2007b:34)

4.3 Development of Energy Performance of Buildings, 2000–2006

4.3.1 Substitution from Fossil Fuels to Renewable Energy

There has been a significant substitution of fossil fuels with renewable energy between 2000 and 2006: fossil share of total energy used for heating decreased from 32% in 2000 to 19% in 2006, while the renewable share increased from 56% to 67% (Swedish Energy Agency and SCB 2003a:2, 2007a:2).[1] In terms of absolute figures, the decrease in fossil fuels has been significantly higher than the increase in use of renewable energy. This implies that although some of the decrease in fossil fuels has been taken by renewable energy, some is due to reduced demand for heating, and some to an increase of nuclear power.

[1] See the calculations in Appendix 2

The reduced use of fossil fuels is due mainly to the significant reduction in the use of oil for heating.[2] In 2000 oil accounted for 22% of the energy used to heat buildings, whereas by 2006 this share had fallen to 8%. (See Figure 4.1.)[3] The decrease is least for multi-family structures and most for one- and two-family houses. However, it is one- and two-family houses that are the major users of oil, and despite the decrease this type of building consumed more oil in 2006 than the two other building types together (Swedish Energy Agency and SCB 2003a:2, 2007a:2). No buildings constructed after 2000 use oil as a heating source, however. Oil boilers have been replaced by other technologies; according to one interviewee, heat pumps and pellets are most employed instead of oil.

The use of bio-energy in absolute figures has shown a small decrease, but when seen in relation to the total energy use it has increased its share by 1% (Swedish Energy Agency and SCB 2003a:2 and 2006a:2). Almost all the use of bio-energy is in one- and two-family houses (93% in 2006). However, bio-energy is also used indirectly in multi-family structures and non-residential buildings, through district heating

The sale of heat pumps has increased greatly – almost 400% between 2000 and 2006.[4] The most significant increase has been for air-to-air heat pumps. In 2000 the sale of air-to-air heat pumps represented only 8% of total sales of heat pumps; by 2006 this share had risen to 41%, exceeding the sales of rock/ground/water heat pumps, which had predominated in 2000 (Swedish Heat Pump Association 2007). One- and two-family houses are the major users of heat pumps: by 2006, 97% of the heat pumps were in this type of building (Swedish Energy Agency and SCB 2007a:10). However, also heat pumps are used indirectly through district heating (Swedish Energy Agency 2007a:25).

District heating increased its share of total energy used for heating from 43% to 53% during the period under study (Swedish Energy Agency and SCB 2002:2, 2007a:2). One- and two-family houses are responsible for most of this increase, as district heating has almost doubled its share of total energy used for heating for this type of building. Despite this increase, almost 90% of the district heating in the building sector is still used by multi-family structures and non-residential buildings. The current trend is for existing buildings to be connected to district heating system, and very few new one- and two-family houses (interview MG).

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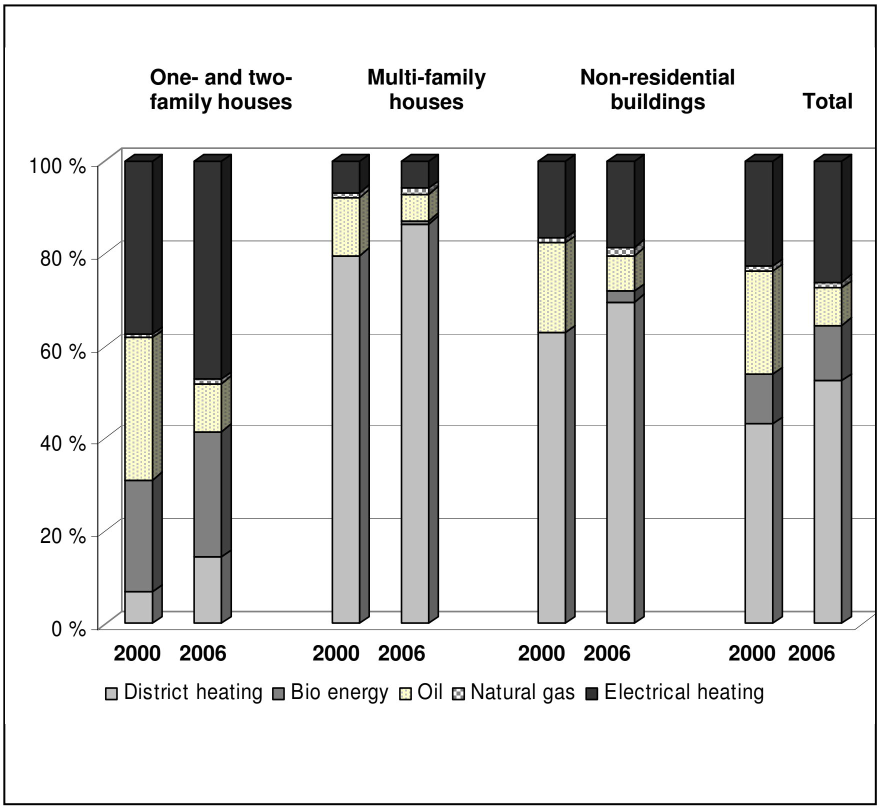
[2] The use of natural gas has remained relatively constant during the period, and represents only 1% of the energy used to heat buildings in Sweden (Swedish Energy Agency and SCB 2003a:2 and 2007a:2)

[3] The use of oil in district heating and electricity production is not included in these figures

[4] The figures may even be larger, as not all sale has been reported to the Swedish Heat Pump Association

Figure 4.1: Energy use in Swedish buildings, by energy carrier and type of building, 2000–2006



Sales of solar collectors increased by 82% between 2000 and 2006 (Ministry of Enterprise, Energy and Communications 2007). However, solar collectors are still not diffused on a wide scale and are only a minor contributor to covering the total energy demand for heating. The main market for solar collectors is one- and two-family houses (interview LA).

CO_2 emissions can serve as an indicator of the substitution from fossil fuels to renewable energy sources in the building sector. From 2000 to 2005, CO_2 emissions from the building and service sector fell by 38% (Swedish Energy Agency 2007a:6–7; figures are available only until 2005).

4.3.2 Conversion from Electrical Heating to Thermal Energy

The use of electricity for heating has risen from 23 to 26% of the total energy used for heating.[5] Also for electrical heating we find significant differences between the building types. Both in 2000 and in 2006, one- and two-family houses used considerably more electrical heating than the two other types. The increase in use of electricity for heating has also been largest for this type of building – from 37% in 2000 to 47% of the total energy used for heating in 2006 (Swedish Energy Agency and SCB

[5] The use of electricity in district heating production is not included in these figures

2003a:7, 2007a:7). For non-residential buildings, electrical heating has had only a small increase while there has been a slight decrease for multi-family structures. (See Figure 4.1.)

The use of electricity for heating can be separated into direct electrical heating and waterborne electrical heating. In one- and two-family houses, direct electrical heating is most common when electricity is the sole source of heating, but not when electricity is used in combination with other sources (Swedish Energy Agency and SCB 2007b:3, 2003b:5). While the number of one- and two-family houses relying solely on electrical heating has decreased during the period, the number of houses using electricity in combination with other energy carriers has increased. This is due to the rise in the number of houses using bio-energy in combination with electricity (both direct electrical heating and waterborne electrical heating).

88% of new one- and two-family houses have electrical heating, and 8% of this is direct electrical heating. Between 1% and 3% of the flats in new multi-family structures have direct electrical heating and 3–5% have waterborne electrical heating (National Board of Housing, Building and Planning 2003b:10). About 7% of the heated floor area in non-residential buildings built after 2000 is heated by electrical heating (Swedish Energy Agency and SCB 2007d:18).[6]

4.3.3 Reduction in Energy Demand[7]

The energy used to heat buildings has been reduced by 12% (Swedish Energy Agency and SCB 2003a:7, 2007a:7). Also here there are differences as to the types of building, with the decrease in energy use greatest for one- and two-family houses (19%) and non-residential buildings (11%), whereas the energy used for heating multi-family structures has been reduced by only 3%.

However, energy use must be studied in relation to the area heated. In 2000, average energy use for heating and hot water per heated area was 153 kWh/m^2/year, while in 2006 the corresponding figure was 137 kwh/m^2/year (Swedish Energy Agency and SCB 2007a:16-18, 2006:17, 2005:17, 2002:17). This decrease is due mainly to the reduction in energy use in one- and two-/ family houses – a 20% decrease in kWh/m^2/year during the period. Non-residential buildings have shown only a minor decrease, and energy use in multi-family structures has remained constant throughout the period.

For residential buildings it can also be relevant to investigate energy use per dwelling. Here the picture changes dramatically: one- and two-family houses used 33% more energy than multi-family structures in 2006, because the heated area in the former type almost was the double that of the heated area in the latter type.[8] On the other hand, examining the

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[6] The statistics for non-residential buildings are not detailed enough to categorize between direct electrical heating and waterborne electrical heating.

[7] Energy demand is calculated by using data for delivered energy

[8] As household size in one- and two-family houses is larger than in multi-family structures, energy use per person is lower in one- and two-family houses

development from 2000 to 2006, we find that one- and two-family houses have shown the greatest improvement.

The differences between building types is less for new buildings, but also for new buildings one- and two-family houses use least energy and multi-family structures the most.[9]

It is difficult to measure the diffusion of technologies that may reduce energy demand, like insulation, the use of energy-efficient windows or the exploitation of passive solar energy. I will instead focus on ‘passive houses’. In 2001 the first passive houses were built in Sweden, and by 2006 the number was 64 (Forum för energieffektiva byggnader 2007).

4.3.4 Summary of the Development of Energy Performance, 2000– 2006

Table 4.1 summarizes the development of energy performance during the period under study. We see there has been a substitution from fossil fuels to renewable energy for all building types, and both existing and new ones. This is due mainly to the significant reduction in the use of oil for heating, and the increase in renewable energy technologies like district heating, heat pumps and bio-energy. For the conversion from electrical heating to thermal energy, the opposite applies: figures for aggregate use of electrical heating show an increase during the period. When we examine the figures for the different building types, the picture gets more complex. There has been some conversion for existing multi-family structures, while existing one- and two-family houses and non-residential buildings have experienced an increase in electrical heating. Also new one- and two-family houses use more electrical heating. As figures for energy demand are not available, statistics for energy use per heated area have been used instead. They show a reduction in energy use per heated area for all buildings, except for existing multi-family structures, where energy use has remained constant.

New buildings may be an indication of the current trends and how technologies are perceived. Unfortunately, the statistics for new buildings are limited, but some general conclusions may be drawn by studying differences between buildings built after 2000 and the existing buildings.[10] Almost all heating systems are waterborne, even though there still is some use of direct electrical heating, especially in one- and two-family houses. As explained, waterborne heating systems allow flexibility and the use of all the various energy carriers. Oil has been completely phased out as an energy carrier in new buildings.[11] On the other hand, a very high proportion of the new one- and two-family houses have electrical heating. Energy use per kwh/m^2/year is quite similar for the three types of buildings, and lower than for the existing buildings. This indicates the use of more energy-efficient building techniques: especially

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[9] See figures in Appendix 6

[10] The energy use of existing buildings is defined as the energy use for all buildings in 2006

[11] Almost no new buildings have had oil-based heating systems since 1970 (Swedish Energy Agency and SCB 2007a)

for multi-family structures and non-residential houses, energy use is substantially lower for new buildings than for existing ones.

Table 4.1: Development of energy performance of buildings, 2000–2006[12]

		Substitution of fossil fuels with renewable energy	Conversion from electrical heating to thermal energy	Reduction in energy demand
New buildings	**One-and two-family houses**	Yes	No, increased use of electricity	Yes
New buildings	**Multi-family structures**	Yes	Yes	Yes
New buildings	**Non-residential buildings**	Yes	Yes	Yes
Existing buildings	**One-and two-family houses**	Yes	No, increased use of electricity	Yes
Existing buildings	**Multi-family structures**	Yes	Yes	Constant
Existing buildings	**Non-residential buildings**	Yes	No, increased use of electricity	Yes

4.4 Techno-economic Factors

4.4.1 The Technological Context

Choices that affect the energy performance of buildings are taken during the design and construction of a building. Due to the long lifetime of buildings in Sweden, many of these choices were been taken long before the period of this study. The technological context is thus the materialization of previous technological choices that affect the possibilities for improving the energy performance of buildings today. Due to low construction rates, replacing the building stock is a very slow process. More than 90% of the buildings that will exist in 50 years have already been built (Ministry of Sustainable Development 2005:39).

In 1970, oil was the major energy carrier in the residential and service sector, representing 72% of the energy use.[13] Since then, the use of oil for heating has decreased significantly and almost been phased out in new

[12] The energy performance of new buildings is defined as 'improved' if they have achieved better results than the figures for all buildings in 2006.

[13] The figures in this section are based on total energy use in the sectors, as statistics do not make further distinctions (also electricity for household and common purposes)

buildings (Energy Market Inspectorate 2006), replaced mainly by district heating, bio-energy and electrical heating. In 2006 the use of oil for heating had been reduced to 10% of total energy use (Swedish Energy Agency 2007a:12– 13). Table 4.2 gives an overview of the development in energy use.

Especially the expansion of district heating systems has been very important for replacing oil (Ministry of Sustainable Development 2005:18). Sweden's district heating program started in 1948, and has expanded continuously since. However, in 1970 oil accounted for 98% of the energy input in district heating systems. The substitution of energy carriers in district heating has therefore been very important for reducing the use of fossil fuels. In 2006 the fossil share in district heating production was only 16% of total energy input.[14] However, to make district heating systems more effective, the construction of combined heat and power plants has attracted considerable attention today.

Also the use of electrical heating has increased significantly since 1970. This has been possible because of Sweden's nuclear power program that started in the early 1970s. From 1970 until 1986, electricity production doubled (Swedish Energy Agency 2007a:20– 21). This led to greater use of electricity for heating, and during the 1970s and 80s the tendency was for new buildings to have had electrical heating (interview KN). Direct electrical heating dominated during the 1970s, while exhaust air heat pumps (classified as waterborne electrical heating) have been common in new one- and two-family houses since the 1980s (Swedish Energy Agency and SCB 2007b:9). While only 7% of residential buildings in Sweden had electrical heating as a main heating source in 1973, this proportion had risen to 26% by 1998 (Unander et al. 2004:1397). Most of this was direct electrical heating (interview). Today hydropower and nuclear power are the major producers of electricity in Sweden, but 5% of the energy input in electricity production came from fossil fuels in 2006. The share of renewables decreased from 59% to 52% between 2000 and 2006.

Total energy use has decreased from 1970 until today, despite a 30% increase in total heated floor area (Johansson et al. 2006). This is due to energy-efficiency measures that have compensated for larger living area, and an increase in the building stock. However, efficiency improvements stagnated during the 1980s (Nässen and Holmberg 2005).

Because of the changeover from oil heating to renewable energy carriers there has also been a decrease in climate gas emissions from the building and service sector. Between 1990 and 2005 the decrease was 54% (Swedish Energy Agency 2007a:6). While 20% of the total CO_2 emissions came from this sector in 1990, this share had been reduced to 10% by 2005 (Swedish Energy Agency 2007a:6– 7).

[14] See Appendix 2 for calculations

Table 4.2: Final energy use within residential and service sectors etc 1970– 2005

	1970	1980	1990	2000	2006
Oil products	118.6	87.3	41.1	30.0	14.9
Electricity	21.9	43.0	65.0	69.0	72.2
District heating	12.1	24.7	30.7	37.3	42.0
Bio-fuels, peat etc.	12.1	9.8	11.2	10.3	13.9
Other fuels	–	–	1.8	1.9	2.4
Total TWh	164.8	164.8	149.8	148.5	145.3
Total TWh, temperature regulated	157.8	161.2	162.4	160.9	150.5

Source: Swedish Energy Agency 2007a:12– 13)

4.4.2 Prices on Energy Carriers and Technologies

Prices on energy carriers and technologies may have a significant influence on the choice of energy carrier for heating buildings: '...the price is very very important' (interview). There are great differences in prices among the various energy carriers.[15] In 2000 electricity was the most expensive, followed by oil, while the cheapest alternative was pellets. Prices for all heating carriers increased from 2000 to 2006, but with some significant differences. The prices of fossil fuels have increased most, due to the rise in prices of crude oil and natural gas and increased CO_2 taxes (Energy Markets Inspectorate 2007:19).[16] Also electricity prices have increased significantly, while district heating has experienced the lowest increase. However, local prices for district heating differ significantly. A price increase may be explained by the rise in prices of electricity and oil, which have made higher prices possible without losing competitive power. Also in 2006 electricity was the most expensive and pellets the cheapest alternative (Energy Markets Inspectorate 2007). However, this may change:

> The prices of bio-energy will increase. Usually the more you produce, the cheaper it gets. But it is not like this for bio-energy. First you take the leftover products and when all the bark and chips are gone you take the next assortment and the next assortment. And the more you increase, the more difficult the assortment gets, and the prices go up. (interview)

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[15] Prices in this section are calculated for a typical one- and two-family house, except for district heating which is for a smaller multi-family house (Energy Markets Inspectorate 2007:19)

[16] From 1997 until 2007 the price of crude oil increased by 113% and CO_2 taxes by 135%.

When substituting from one technology to another, the investment costs may be of great significance. Investment costs for the various technologies have been calculated by the Energy Markets Inspectorate for one- and two-family houses and multi-family structures. Electrical boilers are the cheapest, followed by district heating, while rock-heating pumps are the most expensive (Energy Markets Inspectorate 2007:72).

When energy prices, investment, operation and maintenance costs are added up, bio-energy (pellets) emerges as the cheapest heating alternative for multi-family structures, followed by the rock-heat pump and district heating as third. Electrical and oil boilers are the most expensive alternatives. However, prices differ from one municipality to another, and district heating may be the cheapest alternative some places. The figures also differ for one- and two-family houses, but on average the cheapest alternative is pellets, closely followed by district heating and then the rock-heat pump. Also in one- and two-family houses, electrical and oil boilers are the most expensive alternatives (Energy Markets Inspectorate 2007). However, for buildings that do not have waterborne heating systems, installation costs will come in addition to the costs of the technology.[17]

4.5 Institutional Factors

4.5.1 The Swedish Cultural Context

The motivations for energy efficiency and reducing the use of fossil fuels have changed over the years:

> Sweden has had different political directions over the years. In the 70s we got nuclear power and this led to a surplus of electricity so the government goal was that many should install direct electrical heating. But then they wanted to slowly shut down the nuclear power plants and then the electricity prices rose. And then the government wanted to do something else. It varies all the time. (interview)

The oil crises of 1973/74 led to important changes in Swedish energy policy. Because of the country’s high dependency on oil at that time, main goals were to improve energy efficiency, change from oil to other energy carriers and increase domestic energy production. ‘It was more that we wanted to get rid of the dependence on the oil price than the dependence on oil’, as one interviewee put it.

By 1970 Sweden had exploited most of its hydropower potential, and nuclear power was seen as the solution for increasing domestic energy production (Unander et al. 2004). Sweden had a rapid expansion of nuclear power during the 1970s, but after the Three Mile Island accident in 1979 in the USA, this policy was modified. In 1980 a referendum gave the result that nuclear power should be shut down by the year 2010 and no additional plants were allowed to be built in Sweden (Löfstedt 2001).

[17] The Swedish Energy Agency has calculated the investment to be 40,000 SEK (Ministry of Sustainable Development 2005b:5)

With nuclear power no longer a solution to the energy crisis, other forms of energy production had to be strengthened. The energy produced by nuclear plants would have to be replaced by other energy carriers, and this led to a greater focus on renewable energy. This decision and the uncertainties surrounding alternative energy resources also led to more emphasis on energy efficiency (Unander et al. 2004).

However, during the 1990s Sweden's nuclear power policy was modified. The 2010 target was abandoned in 1997, mainly because of rising electricity prices and pressure from the industry (Wang 2004). To date, two nuclear power reactors have been shut down: Barsebäck 1 in 1999 and Barsebäck 2 in 2005 (Vattenfall 2007). The nuclear debate is still an important political issue in Sweden, and has not yet been settled (see *Dagens Næringsliv* 23 October 2007). Helby (1998) claims that without the decommissioning of nuclear power there will be no need for a large-scale substitution to renewable energy resources. Therefore renewable energy policies will depend heavily on the situation regarding nuclear power.

While the oil crises and later the phase-out of nuclear power marked the start of the emphasis on energy efficiency and renewable energy, climate policy has become increasingly important in recent years. Concerns about climate warming have attracted considerable attention, both among building companies and consumers (interviews). Sweden is a party to the Kyoto agreement, and, according to EU burden-sharing, Sweden is allowed to increase its greenhouse emissions by 4%. In fact, however, the national target is a 4% *reduction* in greenhouse gases, and this target has already been fulfilled – even exceeded. By 2006, greenhouse gas emissions had been reduced by nearly 9% compared to 1990 (Swedish Environmental Protection Agency 2007).

The concern for global warming has led to greater attention to renewables and to energy-efficient technologies. However, technologies still have to be cost-effective if they are to be used, and economic considerations have primacy. 'You can talk about climate and environment and high supply security, but what matters is the price', as one interviewee noted. Others gave greater credit to the concern for global warming: 'All the discussion about global warming and how energy use affects the global climate has the most influence.'

4.5.2 Values and Preferences among Building Companies and Consumers

The previous section discussed how values and motivations for energy policy have changed over the years. However, it is also important to explore preferences and perceptions among the building companies and the consumers. Building companies have traditionally shown very little concern about the energy performance of buildings. The Swedish Construction Federation held a survey some years ago, asking their members to identify the most important environmental issue: very few chose energy. In 2004 they tried to get attention among their members for energy issues, '...but there was no interest at all', reported one interviewee. However, this changed during 2006 due to the increased attention directed at climate change. It is mostly the big building companies that have started to focus on energy and climate, while the smaller ones are still mainly occupied with price considerations. According to several interviewees, the demand for new buildings is high and this leads to less attention to energy performance from the building companies –the buildings will be sold anyway.

Some technologies have gained less support than others among building companies. 'There is scepticism towards passive houses, totally. They don't believe in it, but think that people get sick.' (interview). However, several elements in passive houses, like thicker insulation and energy-efficient windows, are perceived as positive. And at least one housing company has decided that all renovations are to be done with the objective of achieving passive house standard in their multi-family structures (interview).

> There are housing companies that are going to renovate everything to passive house standard; they obviously have energy as a very important focus. It is their duty and obligation to contribute in this way. Others say that if it gets cheaper they can do it, but take no initiative on their own. (interview)

The time perspective is important for carrying out measures that will improve the energy performance of buildings, as investments may have a long payback time. This is a problem, since building companies operate with a very short time-perspective (interview). However, the building companies want a common standard and method for calculating the lifetime costs of a building. Today everybody does their own calculations and it is difficult to compare, for example, during a round of bidding tenders.

The time-perspective is also important for tenants and the possibilities for implementing measures to improve energy performance in rented dwellings. About half of Sweden's residential buildings are rented dwellings (interview). A long time-perspective is necessary for undertaking measures to improve energy performance, but it is a challenge to cover the costs without raising the rent too much. And, as one interviewee pointed out, how shall the tenants take long-term responsibility for improving the energy performance of buildings while they have three months' notice?

The demanders, like the municipalities and private companies, have to require buildings with better energy performance (interview). This is not the case today. Especially for non-residential buildings, energy is not considered important at all. Energy has been too cheap, and other issues have been seen as more important, according to several of the interviewees. An important challenge is thus to increase the demand for buildings with good energy performance. Today this is not an important issue when buying and renting buildings, it was stressed.

4.5.3 Marginal power production

The evaluation of the environmental effects of electricity production may affect perceptions of when and how to use electricity and other energy carriers. The understanding and definition of *marginal power production* has dominated the Swedish debate (interviews). 'Marginal power production' is the electricity production that may disappear as a result of a reduction in energy use, or the opposite: the amount of electricity production that can occur as a result of an increase in energy use (Swedish Energy Agency 2002).

The discussion about marginal power production in Sweden concerns how such power is produced. Some claim that it is imported electricity from coal-fired power plants, others that it is domestically produced electricity from nuclear plants or hydropower. This leads to another important issue: perceptions of nuclear power. Nuclear power does not lead to climate gas emissions and is therefore by some considered an acceptable way of producing electricity. On the other hand, others hold that nuclear power is not an environmentally-friendly way of producing electricity and should be phased out (interviews).

One issue in the discussion about marginal power production is the setting of system borders. The Swedish Energy Agency has defined three possible system borders: Sweden, the Nordic countries and EU. Sweden as a system border may be a fruitful choice if the objective is to study the impacts of a measure on the Swedish emission statistics. However, there is no short-term marginal electricity production for this system border, as marginal power production currently takes place in Denmark or Finland. Because of the deregulation of the power market there is increased cross-border trade of electricity between the Nordic countries. This may indicate that the Nordic countries border is more suitable if the aim is to study how the electrical system works in practice. Connections to Germany, Poland and Russia are not included in this delimitation, which might make the EU system border a better choice. For both the Nordic countries and the EU system border, short-term marginal power production is coal-based condensation (Swedish Energy Agency 2006c).

Another important discussion is whether marginal power production should be used as a measure for evaluating the environmental effects of increased electricity use. A report from the Swedish Energy Agency (2006c) recommended that evaluating the environmental effects of electricity should be calculated by marginal power production. This led to many protests, from among others the Swedish heat-pump association (Energi & miljö 2007), and in 2007 the Swedish Energy Agency removed this recommendation from their webpage. They are currently working on a report that will '...have a more clear application area and give a more nuanced picture' (Swedish Energy Agency 2007).

Marginal power production is also linked to the weighting of energy carriers. This factor is to be individual for the various energy sources, and should mirror the actual environmental effects and conversion losses from production to final energy use (Ministry of Sustainable Development 2005a). This permits summarizing the various energy carriers (Kjellsson 2006) and will be used for evaluating the degree of goal attainment. This work is not finished yet, but is expected to have considerable effect. If electricity gets a high weighting factor, then reduced electrical heating will be emphasized, while a low factor would mean that electrical heating will not be the main focus (interviews).

4.6 Regulative factors

4.6.1 'A good built environment'

Energy efficiency and reduced use of fossil fuels in the building sector have been important policy goals over the years. However, these objectives have been revised several times, also during the period of this study. A 'good built environment' was one of 15 environmental objectives adopted by the Swedish parliament in 1998. The interim target 'energy use in buildings' was revised in 2001:

> The environmental impact of energy use in residential and commercial buildings will decrease and be lower in 2010 than in 1995. This will be achieved, inter alia, by improving the efficiency of and eventually reducing energy use. (Ministry of the Environment 2001b:59)

This goal was later reformulated and strengthened in a new proposition from 2006 where the objective from 2001 was put in terms of accurate measures. By 2020, total energy use per heated area shall be reduced by 20% from 1995 until 2020, and by 50% by the year 2050. By 2020 the dependency on fossil fuels in the building sector is to be broken, while the share of renewables is to keep increasing (Ministry of Sustainable Development 2006:20).

An evaluation of the goals in 2007 stated that the development was leading towards attainment of the previous goals set in 2001, but it was less certain whether the tendency was strong enough to meet the new, more demanding goals (National Board of Housing, Building and Planning 2007).

Conversion from electrical heating to thermal energy is not included in the policy goals or discussed in the reports evaluating these goals and goal achievement (National Board of Housing, Building and Planning 2003a, 2007). However, according to several interviewees, this has remained an important objective over the years.

4.6.2 Building regulations

Building regulations may be an effective policy instrument for reducing energy demand. Sweden's building regulations were first introduced in 1942, but have been revised several times since, most recently in 2006. In that latest revision, the focus changed from primarily setting specific building requirements like non-leakage and insulation, to setting requirements for maximum energy use, defined as energy delivered (interviews; National Board of Housing, Building and Planning 2006). The building regulations set a limit for maximum use of energy, but emplace no requirements as to the choice of heating system or energy carrier. However, for one- and two-family houses that have direct electrical heating as their main heating source, there are maximum requirements for energy use.

Among several interviewees there was a shared understanding that these building regulations apply only to the construction of new buildings. However, an act from 1995 on technical requirements for building constructions states that the requirements for, *inter alia,* energy efficiency are valid for both *building* and *altering* building constructions (SFS 1994).

4.6.3 Taxes and support arrangements

Economic measures have traditionally been the most important policy instrument in Sweden. While building regulations are mainly for new buildings, taxes and support arrangements are directed especially towards the existing building stock. Economic measures that are important in connection with the energy performance of buildings include support for specific technologies, and taxes on energy and CO_2 emissions. Such taxes affect the prices of energy carriers and aim at providing the consumer with incentives for reducing the use of fossil fuels and electrical heating.

The energy tax is applied on several energy carriers, while the carbon (CO_2) tax is limited to fossil fuels. Bio-energy is exempted from the energy tax, but it is applied on electricity, oil and natural gas, among others. The energy tax on electricity used for heating has increased significantly from 2000 to 2006 – by 61%. However, as the price of electricity also has risen during the same period, the tax share of the total price has shown a slight decrease (Skatteverket 2008). Both the energy and the carbon tax are applied on oil. While the energy tax has decreased during the period, the carbon tax has increased. But, although the carbon tax has risen significantly, total taxes on oil have still have increased by a full 83% during the period. Seen in relation to the total price, the tax share has had only a small increase (Swedish Petroleum Institute 2007, Skatteverket 2008).

There have been several support arrangements for improving the energy performance of buildings during the period. Most of these have been for measures to be employed in existing buildings, except for the support to bio-energy appliances and energy-efficient windows in new one- and two-family houses. Other important arrangements include support for substituting from oil heating, for converting from direct electrical heating, for energy-efficiency measures and for installing solar collectors. Some of these arrangements have existed for some time, while others were introduced toward the end of the period under study. Table 4.3 presents an overview of important policy instruments in Sweden from 2000 to 2006.

Table 4.3: Policy instruments in use Sweden today

	Substitution of fossil fuels with renewable energy	Conversion from electrical heating to thermal energy	Reduction in energy demand
New buildings	Economic measures ► Support for bio-energy appliances in new one- and two-family houses (2006→2008) ► Carbon tax on all fuels except bio-fuels and peat (1991→)	Regulations ► Requirements for maximum use of direct electric heating (when it is the main heating source) in one- and two-family houses Economic measures ► Energy tax on electricity used for heating (1951→)	Regulations ► Building regulations Economic measures ► Support for installation of energy-efficient windows in new one- and two-family houses (2004→2008)
Existing buildings	Economic measures ► Support for installation of solar collectors in one- and two-family houses, multi-family structures and non-residential buildings (2000→) ► Support for converting from oil heating to district heating, heat pumps (rock/ ground/water) or bio-energy in one- and two-family houses (2006→2008) ► Carbon tax on all fuels except bio-fuels and peat (1991→)	Economic measures ► Support for converting from electrical heating (1998→2010) ► Energy tax on electricity used for heating (1951→)	Economic measures ► Support for energy efficiency and conversion to renewable energy in public non-residential buildings[18] (2005→2008) ► Support for installation of energy-efficient windows in one- and two-family houses (2006→2008)

Source: National Board of Housing, Building and Planning 2007, National Board of Housing, Building and Planning 2006, Swedish Energy Agency 2006a, SFS 1997

4.7 Summary of the empirical mapping

This study focuses on three different heating systems: direct electrical heating, waterborne heating and passive house concepts. While direct electrical heating can use only one energy carrier – electricity – all the energy carriers and technologies can be employed by a waterborne heating system. On the other hand, the passive house concept makes both of these heating systems superfluous by reducing energy demand to a minimum. During the period under study, waterborne heating systems have been dominant in Sweden, although a significant number of one- and two-family houses have direct electrical heating. The passive house concept was introduced during the period under study, but the number is still low.

[18] 100 million SEK (out of 2 milliards) is for solar cells

The empirical mapping shows that there has been a significant substitution of fossil fuels with renewable energy for all building types, and for both new buildings and existing structures during the period under study. The conversion electrical heating to thermal energy has not been equally successful: we find an increase in electrical heating during the period, but with some differences among the building types. Also for reduction in energy use there is variation, but on the aggregate level there has been a reduction, both for existing buildings and new ones.

This chapter has also explored various factors that may have affected the development of energy performance of buildings from 2000 to 2006. The technological context is an important foundation which creates certain framework conditions for improving the energy performance of buildings. Earlier technological developments have shaped the physical infrastructure in use today, such as the existing heating systems. Also prices on energy carriers and components can have an effect on the diffusion of technologies.

The cultural framework has developed and changed, shaping norms and values. The oil crises, nuclear programs and climate warming have provided important motivations and objectives for policies over the years. These issues are also relevant for understanding the values and preferences among building companies and consumers, and how the various technologies are perceived.

The policy goals have shown ambitious intentions for improving the energy performance of buildings, but no specific targets for conversion from electrical heating to thermal energy. Building regulations are a very important instrument for regulating the energy demand of buildings. Despite the widespread belief that building regulations apply to new buildings only, the empirical mapping has revealed that there is a law stating that there also exist requirements for alterations in buildings. Taxes have been an important instrument in modifying the prices of energy carriers, giving incentives to the use of renewable energy sources. We have also noted that Sweden has a range of support arrangements available for improving the energy performance of buildings.

5 Analysis

This chapter explores the empirical findings in relation to the analytical framework. The first part characterizes the technological system and level of change from 2000 to 2006, relating these changes to the threefold understanding of energy performance of buildings. In the next parts the three explanatory approaches – the techno-economic, the institutional and the regulative – are discussed in relation to the empirical findings. First I explore the explanatory approaches separately, before turning to the co-existence and mutual influence of the approaches in the last part.

5.1 Technological change and energy performance of buildings

Table 5.1 categorizes technologies that affect the energy performance of buildings according to level of diffusion from 2000 to 2006, distinguishing between technological change at the component and the system level. Some changes can be seen on the aggregate level for all buildings, while others are valid for only one type of building.

Most of the diffusion of technologies between 2000 and 2006 has been on the component level. Such changes are characterized by continuity: only the components are substituted, while the system remains the same. Hence, even though some technologies (like heat pumps and solar collectors) have experienced significant increases during the period, this is not a discontinuity but a continuation of the existing technological system. Substituting from oil heating or waterborne electrical heating to renewable and thermal energy requires only changes at the component level, from e.g. oil boiler/electrical boiler to pellets boiler, as the buildings already have a waterborne heating system. According to Unruh (2002), technologies that retain the existing system will have advantages for diffusion, as potential users will perceive them as less radical for with technologies that require changes at the system level.

Changes at the system level require the substitution or replacement of sub-systems. The sub-systems are in this case understood as the heating system: direct electrical heating, waterborne heating systems and the passive house concept. The conversion from direct electrical heating to thermal energy produced by, e.g., solar collectors, district heating or heat pumps (except air-to-air heat pumps) requires emplacing a waterborne heating system. Even though changes at the system level may be perceived as more fundamental than changes at the component level, also these changes can be interpreted as both continuity and discontinuity. According to Unruh (2002), technologies that require the total replacement of sub-systems and represent a radical change from the existing will lead to discontinuity. The introduction of the passive house concept in Sweden may be perceived as such a change, whereas substituting from direct electrical heating to a waterborne heating system can be said to represent continuity as both these systems are widely used in Sweden today. Reduction in energy demand can also be achieved by changes at the component level, like installing energy-efficient windows and thicker insulation. However, full application of the passive house concept makes the traditional heating system superfluous.

Table 5.1: Diffusion of technologies, by effect on energy performance of buildings, 2000– 2006

	Substitution of fossil fuels with renewable energy	Conversion from electrical heating to thermal energy	Reduction in energy demand
Component level	►Reduced use of oil ►Increased use of bio-energy ►Increased use of district heating ►Increased use of solar collectors (one- and two-family houses) ►Increased use of heat pumps (one- and two-family houses)	►Increased use of electrical floor heating (one- and two-family houses) ►Increased use of air-to-air heat pumps (one- and two-family houses	►Reduction in energy use[19]
System level		►Increased use of bio-energy ►Increased use of district heating ►Increased use of solar collectors (one- and two-family houses) ►Increased use of heat pumps (one- and two-family houses)	►Introduction of passive houses in Sweden

Kemp (2002) distinguishes between technologies that make the existing technological system more sustainable, and technologies that represent a new technological regime. This distinction is important as there are limits to the environmental improvements possible within any given technological system (Mulder et al. 1999). There exist two different heating systems within the current technological regime: direct electrical heating and waterborne heating systems. Seen in relation to the concept of energy performance of buildings, the benefits from system optimization differ considerably between these two systems.

It is possible for waterborne heating systems to use only renewable and thermal energy, and this will lead to a complete substitution of fossil fuels with renewable energy and converting from electrical heating to thermal energy. While the waterborne heating systems allow the use of all energy carriers, direct electrical heating locks energy use to electricity. Air-to-air heat pumps are the sole alternative and will lessen the need for electricity. However, as the air-to-air heat pumps use electricity for operating and in addition need supplementary energy (since they cannot cover the entire

[19] It has not been possible to get an overview of the use or sale of components. The figures on energy use show reduced energy use, which indicates that more energy-efficient components have been used.

heating demand), the use of electricity for heating will continue. To some degree electrical heating may be replaced by thermal energy, but not completely, as the total use of electricity for heating would be reduced by only around 15 to 30% (Johansson et al. 2005:1390). The possibilities for substituting fossil fuels with renewable energy using electrical heating depend on the share of renewables and fossil fuels in electricity production and the marginal power production. These issues will be discussed in greater detail below. Neither the waterborne heating system nor direct electrical heating will lead to a reduction in energy demand, but the use of solar collectors or heat pumps will reduce the need for delivered energy. As delivered energy is what is used to calculate energy use, the use of these technologies may be perceived as a reduction in energy demand. However, if the energy carriers are weighted to reflect the actual environmental effects, this may change.

According to Kemp (1994) the technological regime defines certain boundaries for technological progress. As noted above, there are limits to improving the energy performance within the existing technological regime. Hence, changes at the system level may be important for improving energy performance. The introduction of passive houses in Sweden (from 2001) represents a new technological regime, as it is a completely different way of designing and constructing buildings. The passive house concept makes it possible to maintain a comfortable indoor climate without active heating or cooling systems (Passiv Haus Institute 2006).[20] The various elements in passive houses are found in other buildings as well, like insulation, energy-efficient windows and heat recovery. What makes the passive house a regime shift is that these components are put together and optimized according to specific requirements which reduce the energy demand to an absolute minimum, rendering the traditional heating system superfluous. Improvements in energy performance by passive houses far exceed the improvements gained by optimizing waterborne or direct electrical heating systems. As no traditional heating system is required, due to the low energy demand, all the three elements of energy performance will be improved significantly. However, as there are still very few passive houses in Sweden, the passive house concept has led to only minor improvement in the aggregate energy performance during the period under study.

Even though the existing technological regime emplaces certain limits on improving energy performance, there is still great potential, especially within the waterborne heating system but also in direct electrical heating, both for substituting fossil fuels with renewable energy and converting from electrical heating to thermal energy. It is also possible to improve and replace components like windows and insulation, to reduce the demand for energy. Most improvement in energy performance between 2000 and 2006 has taken place within the existing technological regime, except for the small number of passive houses built. It is first and foremost changes at the component level that have led to the greatest improvements in energy performance during the period. Oil has been generally replaced by district heating, but also electrical heating

[20] A heat exchanger is needed to recover the heat from the exhaust air

(particularly for one- and two-family houses) and bio-energy.[21] There is still a potential for improvement within the current technological regime, especially for the replacement of fossil fuels by renewable energy and the switch from electrical heating to thermal energy. Also energy use may be reduced, but a regime shift will offer significantly higher potential.

The explanatory approaches will be used to explore the development of energy performance of buildings further. As shown by the empirical mapping, there has been a substitution of fossil fuels with renewable energy and a reduction in energy use, but not a change from electrical heating to thermal energy. The spread of technologies that have affected this development was outlined in Table 5.1. The remainder of this chapter looks into the development of the three different elements of energy performance of buildings and the diffusion of technologies that have affected this development.

5.2 The techno-economic approach

The techno-economic approach emphasizes that the power to effect change is imputed to the technology itself (Marx and Smith 1994). Both the existing technological system and the technologies have inherent attributes which give them advantages as well as disadvantages for diffusion. Also the prices of energy carriers and technologies influence the possibilities for improving the energy performance of buildings. Three techno-economic factors will be explored: the physical infrastructure, attributes of the technologies, and prices and costs. This section will discuss whether these techno-economic factors have promoted or prevented improved energy performance of buildings in Sweden from 2000 to 2006 and may offer explanatory power to the empirical findings outlined in the previous chapter.

5.2.1 Physical infrastructure

One of the elements that influence the possibilities for diffusion of technologies is the physical infrastructure (Kemp 1994). This infrastructure is the result of previous technological change and influences the possibilities for improving the energy performance of buildings by giving advantages to some technologies and disadvantages to others. Thus the technological context is essential for explaining the physical infrastructure and how it has affected the possibilities for improving the energy performance of buildings. Today's existing buildings may also be perceived as central elements of the physical infrastructure. The empirical mapping revealed great differences between the various types of buildings. May the explanation for this variation be found in physical attributes of these types? Both the technological context and building type may be perceived as technological trajectories which influence the possibilities for diffusion of energy technologies. They may create lock-in, as changes outside the trajectory are difficult.

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[21] Based on changes in the energy carriers share of total energy used for heating

Technological context

The technological context is important for understanding the existing technological system. Previous technological change has shaped the physical infrastructure and creates certain framework conditions that may favour or disfavour various technologies. It is not possible to change the technological context in the short term, since it is the result of years of previous technological developments. However, technological change today will influence the technological context in the longer term.

As noted above, the heating system is essential for the possibilities for improving the energy performance of buildings. The heating system is decided when a building is being designed and constructed; due to the long lifetimes of buildings in Sweden, the technological context may provide an explanation for the main heating systems in use today: direct electrical heating and waterborne heating systems. It is of course possible to replace heating systems, but this is an expensive and extensive procedure.

In 1970 oil was the main heating source in Swedish buildings, which also resulted in a high share of waterborne heating systems. This has reduced the costs of replacing oil boilers with other technologies like district heating and heat pumps, as the infrastructure was already in place. As explained above, a waterborne heating system allows the use of all the energy carriers. In addition, because the use of oil in new buildings has decreased significantly after 1970, most oil boilers today are old and in need of replacement (Energy Market Inspectorate 2006). The costs of switching from oil boilers to renewable energy technologies become significantly lower if these boilers would have to be replaced anyway.

The nuclear programs and significant growth in domestic electricity production led to increased use of both direct electrical heating and waterborne electrical heating in one- and two-family houses during the 1970s and 80s. It is important to distinguish between direct electrical heating and waterborne electrical heating, as these two systems provide different opportunities for changing energy carriers. In buildings with direct electrical heating it is possible to install a waterborne heating system, and thus covert to thermal energy. As this is very expensive, the cheapest alternative in the short term is air-to-air heat pumps. As the main use of direct electrical heating is in one- and two-family houses, this may help to explain the why almost all air-to-air heat pumps (97%) are employed in this type of building. This creates lock-in, as electricity is the only energy carrier that may be used. But it does not explain why one- and two-family houses also are the major users of other heat-pump types which require a waterborne electrical heating system. On the other hand, even though electricity is still needed (as input for the heat pump and as supplementary energy), total electricity use will be reduced. This conflicts with the findings of this study: an overall increase in electricity used for heating. Other factors must have compensated for and counteracted this reduction.

Energy use in existing buildings, especially multi-family structures, is significantly higher than for buildings constructed after 2000. Due to the long lifetime of buildings, many of today's existing buildings were constructed before the attention to energy security and energy efficiency escalated in the 1970s. The 'million programme' houses – referring to the large-scale construction of houses (about 110 000) in Sweden from 1965 to 1974 (Lago 2004) – use approximately twice as much energy as new multi-family structures. These buildings were constructed rapidly without much concern for quality. In addition, measures to reduce the energy demand in existing buildings are both more limited and more expensive than for new buildings (see Table 2.1).

Our discussion about the impact of the technological context on the development of energy performance of buildings has concluded that previous technological developments have affected the development of energy performance by determining the heating systems found in existing buildings. This context promotes the substitution of fossil fuels with renewable energy, but not the conversion from electrical heating to thermal energy. The possibilities for reducing energy demand are much more limited for the existing building stock than new buildings. Due to long lifetime of the existing building stock, this works against reductions in energy demand.

Building type

The differences in energy performance between the building types may indicate that the possibilities for improving the energy performance are related to building type. In this section I will discuss whether the various types of buildings have special attributes which make it easier or harder to improve energy performance.

First, a recap of the empirical findings on differences between building types related to the replacement of fossil fuels with renewable energy. One- and two-family houses had the largest substitution from 2000 to 2006. This involved the largest increase in energy technologies like heat pumps, solar collectors, district heating and electrical heating and the most significant decrease in the use of oil for heating. However, in 2000 this type of building had the highest share of fossil fuels and lowest share of renewable energy, and thus also the greatest potential for improvement. The significant improvement of one- and two-family houses brought this type of building ahead of multi-family structures in 2006 as regards the lowest share of fossil fuels. Non-residential buildings have a similar energy structure as multi-family structures, but a slightly higher share of fossil fuels and a somewhat smaller share of renewable energy. Here I will concentrate on one- and two-family houses and multi-family structures, as the differences between these two building types are greatest.

Regarding energy technologies, the major difference between one- and two-family houses and multi-family structures concerns district heating. The infrastructure is expensive and demands large investments which require a certain number of connections to be profitable. The more buildings that connect to the district heating system at the same time and in the same area, the more it becomes economically profitable (Persson and Sernhed 2004). This favours multi-family structures, as, by definition, this type of building has higher density. However, district heating for one- and two-family houses has increased during the period and almost doubled its share of the total energy used for heating for this building type. As also 10% of new one- and two-family houses built after 2000 have district heating, building type cannot provide the whole explanation for the differences found. According to one interviewee, district heating may be used in all urban areas. (An 'urban area' is defined as having more than 200 inhabitants and no more than 200 meters between the buildings (SCB 2006)). The type of building is therefore not decisive, as one-and two-family houses also can be located in urban areas. '...Only in an area with only one-family houses it does not pay off to build out district heating...' (interview). District heating is not yet common in Sweden's smallest urban areas, but about 80% of the urban areas with 3000+ inhabitants have a district heating net today (Euroheat & Power 2007).

Multi-family structures have been the main market for district heating, due to the lower costs of connection. Other renewable energy technologies have competed for shares in the market for one- and two-family houses, and this may explain the increase in diffusion of technologies like heat pumps and solar collectors. These technologies may also be used in multi-family structures, but have been locked out due to the predominance of district heating. The energy use of buildings built after the year 2000 may be useful for exploring the potential for substituting fossil fuels with renewable energy. Oil has been completely phased out in new one- and two-family houses and multi-family structures, while there is some use of natural gas. The conclusion from our discussion on type of building and the substitution of fossil fuels with renewable energy is that building type does affect the possibilities of the various technologies, but not the possibility for completely replacing fossil fuels with renewable energy. Some technologies are better suited for multi-family structures and non-residential buildings than for one- and two-family houses, and vice versa.

We also find great differences between one- and two-family houses and multi-family structures when it comes to electrical heating: one- and two-family houses use significantly more than do multi-family structures. This tendency has become stronger from 2000 to 2006. As noted above, all thermal energy technologies may be used in both building types, and the differences in use of electrical heating cannot be explained by attributes inherent in the building types.

Also for reduction in energy use the two building types differ. For 2000, energy use per kWh/m^2/year is not very unlike, but by 2006 energy use had been reduced significantly for one- and two-family houses while remaining constant for multi-family structures. However, the differences between the building types are very small for buildings constructed after 2000. This implies that it is not attributes inherent in the building types that may explain the differences, as one- and two-family houses and multi-family structures may be constructed with similar energy use. This is also confirmed by the fact that it is possible to build both one- and two-family houses and multi-family structures to passive house standard.

However, when discussing the importance of building type, kwh/m^2/year may not be the best measure for energy use, as buildings with a large heated area are likely to have lower energy use per square meters. Instead, energy use per dwelling unit may be a more appropriate measure. The empirical mapping concluded that the energy use per dwelling unit is significantly lower for multi-family structures than for one- and two-family ones. On the other hand, it is certainly possible to construct one- and two-family houses with heated area the size of that in multi-family structure, and vice versa. Hence, the type of building is not decisive in this case either, although multi-family structures are likely to have lower energy use per dwelling unit than one- and two-family houses.

Thus we see that the type of building has not affected the possibilities for substituting fossil fuels by renewable energy or converting from electrical heating to thermal energy, but, due to the higher living area in one- and two-family houses, the type of building does affect the possibilities for reducing energy demand.

5.2.2 Attributes of the technologies

Inherent attributes of the technologies will influence their possibilities for diffusion and the degree to which they will improve energy performance. One important attribute that affects the latter is the renewable and fossil share of the energy input involved in the technology. Feasibility is used as a common characteristic of attributes related to usability, suitability or complementarity. These factors may be connected to what Arthur (1988) refers to as increasing returns to adoption which promote the use of already widespread technologies.

Energy input

As discussed in the previous section, it is possible to effect a complete substitution of fossil fuels with renewable energy for all building types. However, there are some differences among energy technologies when it comes to the possibilities of fulfilling this potential, due to the share of renewable and fossil energy input. District heating and electrical heating are the two most important energy technologies, representing almost 80% of the energy used for heating buildings in Sweden. Changes in energy input may therefore have great impact on the substitution of fossil fuels with renewable energy.

Energy inputs in district heating and electricity production are both fossil fuels and renewable energy (as well as nuclear power). Substituting from fossil fuels to renewable energy in buildings using district heating and electrical heating will therefore depend on the energy input. There has been some substitution of fossil fuels with renewable energy carriers in district heating production from 2000 to 2006, but 16% fossil fuels remain. However, it may be expensive to substitute the last remaining oil use, as these boilers are used only to cover peak demand on the coldest winter days. 'It would have to be a cheap rebuilding as they run little...' (interview). There is an ongoing discussion about the possibilities of switching to bio-oil in these boilers (interview). The fossil share in district heating prevents the substitution to renewable energy due to the widespread use of district heating in buildings. This also has a considerable impact on the aggregate level due to the high number of buildings connected to district heating. The share of renewables in electricity production has decreased from 2000 to 2006, while the fossil share has remained constant. This is due to a reduction in hydropower and an increase in nuclear power in 2006 compared to 2000. It is important to also bear in mind that theses figures show only domestic electricity production. If imported electricity is included, fossil fuels may emerge with a larger share. While the changes in energy input for district heating lead to a substitution of fossil fuels with renewable energy, the changes in input for electricity production have counteracted this substitution.

Unlike district heating and electrical heating (including heat pumps), the switchover to bio-energy and solar collectors will give a complete substitution of fossil fuels with renewable energy. However, despite the significant increase in sales of solar collectors, they are still only a minor contributor to covering energy demand in Swedish buildings. Also bio-energy has had a slight increase during the period and is responsible for a small part of the substitution.

The need for of electricity to run the heat pumps brings this technology into conflict with conversion from electrical heating to thermal energy. This is particularly true of the heat-pump types that can cover only a small portion of the energy demand, like air-to-air heat pumps. Switching from electrical heating to heat pump will reduce the use of electricity for heating, but if the previous energy carrier was oil, the use of electricity will be increased. There are other renewable heating technologies that do not use electricity, like solar collectors, bio-energy and district heating. These can improve the energy performance of a building more than the use of heat pumps.

The significant increase in heat pumps may explain the reduction in energy use during the period, as only the energy delivered is accounted for in the energy statistics. As the energy out put from a heat pump is three times more than its input, two-thirds of the energy is ‘free’. This may be an incentive for installing heat pumps. When oil heating or electrical heating is replaced with heat pumps, energy use will be reduced by two-thirds. However, electricity use has risen for one- and two-family houses, which may indicate that heat pumps have replaced oil more than they have replaced electrical heating.

The energy input of the technologies affect the energy performance of buildings in several ways. Renewable energy input has increased during the period, promoting the substitution of fossil fuels with renewable energy, while the change from electrical heating to thermal energy has been inhibited due to the input of electricity in heat pumps. The amount of energy delivered will be reduced in buildings using solar collectors and heat pumps. However, this has no effect on the overall energy demand of the building.

Feasibility

Several technologies compete for shares in the Swedish heating market. Most of these are already widely diffused, like district heating, bio-energy and electrical heating, whereas solar collectors still have a very small share of the total heating market. According to Arthur (1988), technologies already in use on a large scale have gained benefits which give them advantages compared to less diffused technologies. Technologies that have been around for a long time have been integrated into the technological system and have undergone improvements that have made them more cost-efficient, energy-efficient and user-friendly. The diffusion of less familiar technologies like solar collectors and passive houses may have been inhibited by this factor.

The ability to cover the entire heating demand is one of the main differences among the various technologies. The most widely diffused ones – district heating, bio-energy and electrical heating – have this ability, while solar collectors and most types of heat pumps need supplementary energy. Heat pumps have become increasingly efficient and can provide a higher energy output than before (interview). This improvement may be related to one of the benefits identified by Arthur (1988): learning by using. Another important difference is user-friendliness and the need for maintenance. District heating and electrical heating (including heat pumps) are perhaps the most user-friendly technologies, while the use of bio-energy requires continuous maintenance. How much will depend on the choice of pellets boiler, and the use of automatic boilers will reduce the workload significantly.

Another source of increasing returns to adoption is economies of scale in production: the fall in costs per unit as production increases. For bio-energy the situation is different. A tree can be used for three different purposes: timber, paper pulp and the leftovers for bio-fuels. Increased demand for bio-fuels leads to greater competition between the heating market and timber- and paper pulp industries over the raw materials.

Hence, we see that the differences in the advantages of the diffused technologies are due first and foremost to inherent attributes of the technologies, and only some degree increasing returns to adoption. These attributes promote the substitution of fossil fuels with renewable energy, but work against the conversion from electrical heating to thermal energy.

5.2.3 Prices and costs

According to Freeman (1991) the economic elements of the selection environment is the most important for the diffusion of technologies. This was confirmed by several of the interviewees, who stated that financial considerations were perhaps the most important factor for both consumers and building companies when choosing heating systems, energy technologies and measures to reduce energy demand. However, the prices on energy carriers and components are not determined by the technical side alone. Regulative elements like taxes, subsidies and support arrangements alter the prices and total costs for the buyers. This section will discuss the impact of the total price, while the taxes and support arrangements will be discussed later under the regulative approach.

There are great differences among the technologies regarding prices on energy carriers and components. Prices that favour renewable energy carriers may be an important factor for the substitution of fossil fuels with renewable energy. However, the empirical material reveals that there is no connection between price level and substitution. The highest price is for electricity – which has increased significantly in one- and two-family houses. By contrast, the energy carrier with the lowest price during the period, bio-energy, has actually decreased in absolute figures, and has had only a very small increase in its share of total energy used for heating.[22] However, the increase of prices is more in accordance with the diffusion of energy carriers. Oil was both among the most expensive energy carriers during the period, and has also increased significantly in price from 2000 to 2006. This is in line with the empirical findings that show that the use of oil for heating has decreased significantly during the period. The development of prices on district heating supports this, as these prices have had the least decrease, while it has increased its share of total energy used for heating.

As noted earlier, the improvement of energy performance will demand substitution of components and also, in some cases, substitution of the heating system itself. The prices of energy carriers must therefore be studied in relation to the costs of components and investments in heating systems. The investment of a new heating system will normally be paid back in the long term due to the development of energy prices and level of investment costs. The low investments for direct electrical heating compensate for the high electricity prices and may offer explanation for the increased use of electrical heating. Also for waterborne systems, the electrical boiler is the least expensive alternative (Energy Market Inspectorate 2007:26).

The choice of heating system and energy carriers must also be seen in relation to the heating demand of a building. Energy-efficient building techniques like thicker insulation and energy-efficient windows have often higher costs than conventional techniques: both because of the investment costs and because energy prices are too low for the reduced energy use to compensate for the higher investment costs. This serves to counter the use of techniques that are not cost-efficient, as financial considerations are very important for building companies. In the long term, these investments may still be profitable, but building companies operate with a very short time-perspective (interview). Low energy demand in new buildings due to energy-efficient building techniques makes the repayment time longer for technologies with high investment costs. This favours the air-to-air heat pump (interviews). In other words, the improvement of one of the elements of energy performance of buildings acts to prevent improvement in another element: the conversion from electrical heating to thermal energy. Solar collectors demand large investments and can in addition cover only a part of the heating demand of a building. This may be a barrier to the wider spread of solar collectors (interview). However, also air-to-air heat pumps need a high share of supplementary energy, but the investment costs are significantly lower

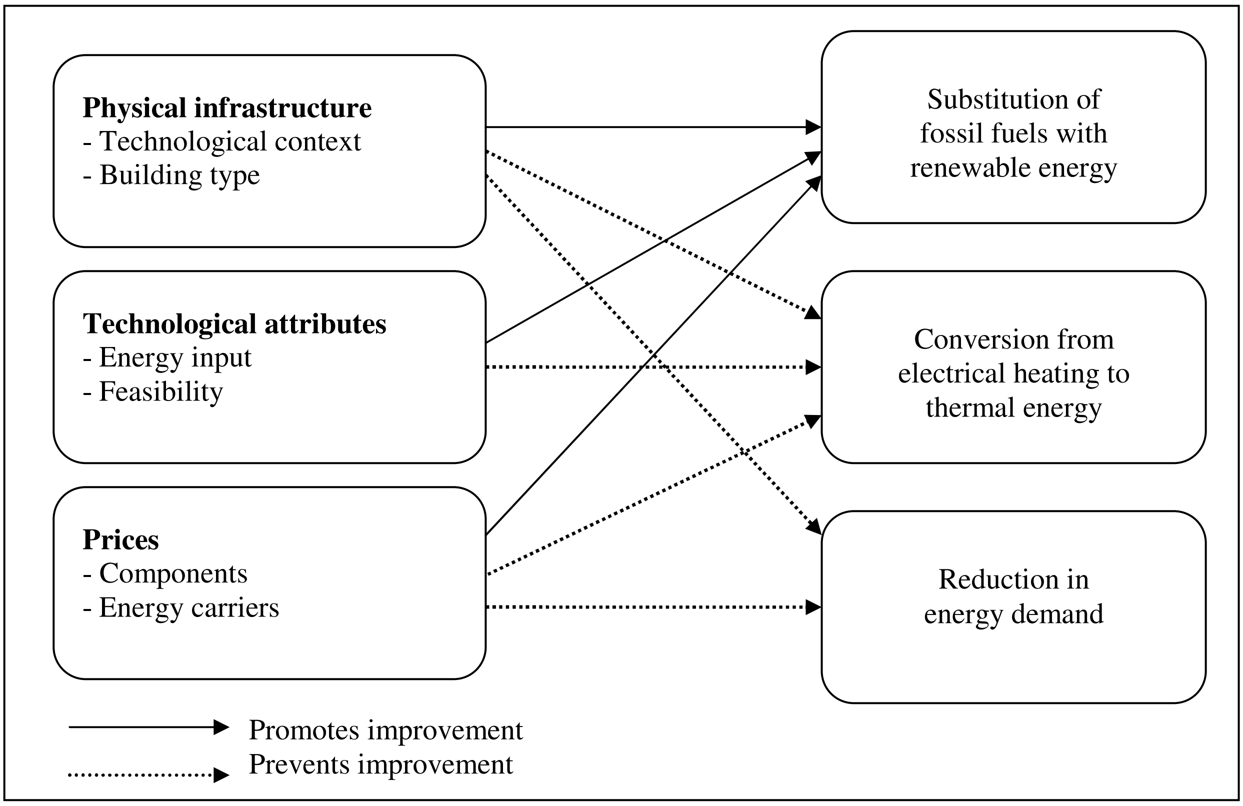
[22] The prices are for pellets

than for solar collectors. Both solar collectors and heat pumps get 'free' energy from the surroundings which lower the variable energy costs. This may compensate for the high investments for solar collectors, but heat pumps will still have advantages because of their lower investment costs.

Substituting from fossil fuels to renewable energy has lower costs, as the heating systems as such can remain unchanged and only components substituted. Renewable energy carriers are also less expensive than fossil fuels. The costs involved, however, act to prevent the conversion from electrical heating to thermal energy, especially for buildings with direct electrical heating and those with low energy demand. Low energy prices have made measures to reduce energy demand less profitable, due to the long payback times involved.

5.2.4 Summary of techno-economic factors

Figure 5.1: Influence of techno-economic factors on the improvement of energy performance of buildings, 2000-2006



However, the conversion from electrical heating to thermal energy has been discouraged by all the factors. Direct electrical heating in one- and two-family houses locks the energy use to electricity. It is possible to install a waterborne heating system, but the investment is expensive. Also for new buildings, electrical heating is the least expensive alternative.

Reduction in energy demand is also inhibited by techno-economic factors. The type of building is important for reducing energy use, as multi-family structures use less energy per dwelling than one- and two-family houses. However, changing the building structure is very much a long-term task. Also the costs of energy and components act to prevent a reduction in energy demand, as energy-efficiency measures may have a long payback time due to high costs and low energy prices.

5.3 The institutional approach

The institutional approach stresses the importance of studying technological change in relation to cultural factors. Especially in complex technological systems, the selection of technologies is heavily influenced by institutions (Rosenkopf and Tushman 1994). Path-dependency is a result of positive feedback mechanisms which trigger additional development along the same direction as previously. The spread of technologies that conflict with this path will be prevented, while technologies that are in line with the current institutions will be promoted. This section looks into the explanatory power of the institutional approach for the development of energy performance of buildings. Three institutional factors are explored: the Swedish cultural context, perception of technologies, and supplier–demander relations. For the institutional approach to have explanatory power, these factors must prove to have influenced the development of energy performance of buildings.

5.3.1 Swedish cultural context

As explained by Scott (2001), the cultural framework is a wider belief system that shapes the subjective interpretations and the actions of individuals and organizations. The cultural context has developed over time and thus given different meanings to energy performance of buildings. This has led to various motivations for improving the energy performance over the years, which again have had varying for the three elements of energy performance. Is the main goal to reduce climate gas emissions, or to increase energy security? Shall nuclear power be phased out, or is this climate-neutral energy production that can be continued? These are central questions which have been answered in various different ways over the years. These answers have shaped the understanding of energy performance of buildings and also created a framework that may have affected the development of energy performance during the period under study.

The global warming issue has received considerable attention in Sweden in recent years. While energy security was the main reason for improving the energy performance of buildings after the oil crises in 1973/74, the climate debate has become increasingly important since the early 1990s. This has led to greater emphasis on the elements of energy performance that directly influence the Swedish ‘climate account’: the substitution from fossil fuels to renewable energy, and reduction in energy demand. Despite differing motivations, the emphasis on energy security and on climate change both promote improved energy performance of buildings. As the two objectives are not conflicting, they have reinforced each other and may have speeded up the replacement of fossil fuels with renewable energy.

Nuclear power has a key part in discussions of energy performance of buildings in Sweden. Since the first power plant was built there has been considerable debate about the decommissioning or continuation of nuclear power. This discussion continues, and has taken a new turn with the climate debate. At a time when reducing climate gas emissions has received main attention, nuclear power has been given a second chance, as the electricity production from nuclear power is CO_2-neutral. As a mere 5% of Sweden's electricity production was from fossil fuels between 2000 and 2006, the use of electricity leads to only minor climate gas emissions. This may indicate that the use of electrical heating is not perceived as a major problem in Sweden, and may help to explain the increase in electrical heating that the empirical mapping revealed.

Energy security and increased domestic energy production are still important issues in Sweden. However, while the main objective of the district heating program has been to provide buildings with heating, the primary purpose of combined heat and power plants is electricity production (interview). The heavy emphasis on electricity production can also be found in the focus on solar energy. Even though solar collectors have significantly higher energy-conversion efficiency than solar cells in Sweden, solar cells have greater political interest, as electricity can be used for a range of purposes (interview). The main focus of attention today is on electricity production, not thermal energy. The heavy emphasis on electricity may offer some explanation to why the use of electrical heating has increased during the period. Perceptions of electrical heating are discussed more in the next section.

We see that Swedish cultural context has had implications for the development of energy performance. The increase in attention to climate change has led to a greater focus on substituting from fossil fuels to renewable energy and on reducing energy demand, but it has also meant increased acceptance for nuclear power and electrical heating.

5.3.2 Perceptions of technologies

People's preferences and beliefs are elements of the selection environment that influences how technologies are perceived (Kemp 1994). These beliefs may be crucial for technology diffusion and will therefore also affect the development of energy performance of buildings. How technologies are perceived has had significant influence on the substitution of fossil fuels with renewable energy, as the use of oil for heating is not regarded as appropriate in Sweden today. This is due primarily to '...the awareness that we have to get away from dependency on fossil fuels, for the sake of the climate...' (interview). As various renewable energy technologies compete for shares in the heating market, the perception of technologies may help to explain why some have become more widely diffused than others.

Solar collectors are the technology with least environmental impact, as they completely run on renewable energy. Thus, use of this technology will lead to the greatest substitution of fossil fuels with renewable energy. Even though the technology has existed in Sweden since the 1980s, knowledge about solar collectors is still not widespread. This is primarily what has stood in the way of diffusion, not that people are sceptical or negative towards the technology. As there exist several other better-known, more widely diffused technologies, consumers tend to prefer them (interviews). This is an example of how technologies that are diffused on a large scale become even more attractive through informational increasing returns that inhibit the diffusion of less familiar technologies.

District heating has a long tradition in Sweden and has expanded continuously since the 1950s. However, there is also scepticism to being connected to a district heating net. District heating is a natural monopoly, as the investment for infrastructure is high and variable costs are low (Energy Markets Inspectorate 2007). Even though there exist several alternatives for heating and it is possible to disconnect, once the infrastructure has been installed it is difficult to change to another energy technology (interview). 'Customers feel it's a little like a monopoly and that they are stuck. This is why they sometimes choose not to connect' (interview). However, district heating increased its share significantly from 2000 to 2006, so this critique has only to some degree worked against the diffusion of district heating. Since fossil fuels are not generally perceived as a realistic option, heat pumps and bio-energy are the main competitors to district heating and solar collectors. Scepticism towards solar collectors and district heating has therefore mainly influenced the choice of technology, not prevented the substitution of fossil fuels with renewable energy.

Making the conversion from electrical heating to thermal energy is heavily influenced by how electrical heating is perceived. Several interviewees referred to the debate about electrical heating versus thermal energy as a philosophical issue. On the other hand, the relationship between energy forms and purpose is a central issue in physics. According to the laws of thermodynamics, when energy is transformed its quality deteriorates (see Holter et al. 1998). Energy quality is higher for electricity than for the other energy carriers as it can be used both for mechanical work and heating. However, this has not been a central issue in the Swedish discussion about electrical heating. The main focus and pros and cons for using electricity for heating relate to the understanding of marginal power production, and thus whether greater use of electrical heating leads to more climate gas emissions or not.

It is therefore first and foremost the perception of marginal power production that influences the use of electrical heating in Sweden. If electricity is understood as a scarce resource and it is believed that greater use of electricity will lead to more electricity production from CO_2-emitting coal-fired power plants, converting from electrical heating to thermal energy will be important. If, however, electricity is seen as CO_2-neutral because it is produced by hydropower or nuclear power, conversion will not be the main issue for improving the energy performance of buildings. This aspect is central for evaluating electrical heating and heat pumps, as both systems use electricity to produce thermal energy.

The system border is essential in the discussion about marginal power production. If the system border is set to Sweden, only electricity production in Sweden is included, whereas setting it to the Nordic countries or to the EU will include imported energy. A report from the Swedish Energy Agency (2002) concluded that most of Sweden's marginal power production came from coal-condensation energy from Denmark, Finland and Germany. Since then, this view has been moderated; however, no alternative marginal power production has been launched, as one is awaiting the results of an inquiry about weighing factors (interview). The discussions about marginal power production and weighing factors indicate that the question of electricity for heating has been a long-standing issue which is still not resolved. Acceptance of electrical heating has fluctuated over the years. However, the empirical material gives indications of growing acceptance of electrical heating during the period studied. This is also in line with the empirical findings: increased use of electrical heating.

When it comes to reducing the demand for energy there exist several technologies that may prove far more effective than those widely used today, like applying the passive house principles on both new buildings and when renovating existing buildings. 'It is a very conservative construction industry. They take what is cheapest and easiest. Then they can build fast without giving one little thought to energy use' (interview). Scepticism to passive houses among building companies may have slowed down the diffusion of this concept. This building concept represents a radical change and a new technological regime, and thus also requires changes in the institutions (Unruh 2002). This scepticism is an example of institutional inertia slowing down the process of diffusion. However, the changes in values by 2006 due to awareness of climate change may have reversed this lock-in and perhaps helped to speed up diffusion.

Our discussion on perception of technologies has revealed several implications for energy performance of buildings. Oil is no longer regarded as an appropriate energy carrier, and despite scepticism and little knowledge about some of the renewable technologies, the substitution of fossil fuels is promoted because several other renewable alternatives are available. On the other hand, the conversion from electrical heating to thermal energy goes slowly because a focus on energy quality and forms is absent from the Swedish debate. To some degree, the focus on marginal power production works against the use of electrical heating, but as the understanding of the marginal power production is vaguer than before, the use of electrical heating is promoted. And finally, achieving a reduction in energy demand is hampered by the scepticism towards the passive house concept.

5.3.3 Supplier–demander linkages

Kemp (1994) defines supply–user linkages as important elements of the selection environment influencing the diffusion of technologies. The building sector consists of several different actors, and can be divided between suppliers and demanders. Suppliers may be building companies and companies selling and installing technologies, while demanders are the owners, buyers and tenants of the buildings. Both the preferences of these actors and the connection between them may influence the development of energy performance of buildings.

According to several of the interviewees, energy performance of buildings was not an important issue for building companies or demanders until 2006. Economy and comfort have been in focus. This has led to a self-reinforcing pattern, as the building companies follow the consumers' requests, while the high demand for housing makes consumers less interested in the actual qualities of the building. Even though energy has not been an explicit issue, the current path dependency is a result of the cultural context discussed earlier, which especially integrates the substitution of fossil fuels with renewable energy while blocking the changeover from electrical heating to thermal energy.

As noted previously, lack of sufficient knowledge may be a barrier to the wider spread of solar collectors. On the other hand, according to one interviewee, the companies that install solar collectors represent the greatest bottleneck: 'The problem is that if you are a private individual with a one-family house, and you want solar collectors and contact an installation company, they have neither the time nor the interest' (interview). This is due to the high pressure on the building market: '...then you are not interested in new techniques' (interview). When neither the suppliers nor the demanders have the knowledge, and several other more familiar alternatives are available, the diffusion of solar collectors slows down. This is a vicious circle and an important barrier to diffusion.

The increased attention to energy and climate change in 2006 may be interpreted as changes in taste, one of the extraordinary events defined by Cowan and Hulten (1996, in Unruh 2002) that may overcome lock-in. This focus has broken the previous path dependency, as several building companies and demanders have now put energy efficiency on the agenda. This change is an important driving force for improved energy performance of buildings, but has occurred too recently to have had any noteworthy effect of the development of energy performance of buildings during our period of study, 2000 to 2006.

When evaluating the payback time for the extra costs of technologies that improve the energy performance of buildings, the time-perspective is essential. The diffusion of technologies with high investments and long payback time will be prevented by the short time-perspective among building companies and demanders alike. The lack of a common standard and method prevents a longer time-perspective and the inclusion of life-cycle costs (interview).

The time-perspective is especially a problem when it comes to improving the energy performance of rental dwellings. The tenant is the one that benefits from lower variable energy costs, while the one who pays for the technology, the landlord, does not get any of the benefits. Transferring the costs by raising the rent may be opposed by the tenants, due to the short time-perspective. Rents in Sweden are set in negotiations between landlords and tenants' representatives. This system hinders the application of energy-efficiency measures. Most rental dwellings are located in multi-family structures (SCB 2008), and, due to the high share of renewable energy and low use of electrical heating in multi-family structures, this especially influences the reduction in energy demand. Hence, this may offer some explanation for the higher energy use per kWh/m^2/year in multi-family structures. Including energy efficiency in rent negotiations may be crucial for securing a reduction in energy demand in rental dwellings. The lack of a common standard for integrating the lifecycle costs of buildings, and not including energy efficiency in rent negotiations, are examples of how administrative barriers act to prevent improved energy performance. This is in line with the claims of Mulder et al. (1999) on the importance of changes in organizations and management for radical technological change.

To conclude our discussion about the impact of supplier-demander linkages on the development of energy performance of buildings: even though energy issues have not been important for building companies or the consumers, the focus on energy performance discussed under the Swedish cultural context has been integrated in values and preferences. However, this leads to incremental substitution of fossil fuels with renewable energy and reduction in energy demand, but works against the introduction of radical improvements in these elements and against the conversion from electrical heating to thermal energy.

5.3.4 Summary of the institutional approach

Figure 5.2: Influence of institutional factors on the improvement of energy performance of buildings, 2000-2006

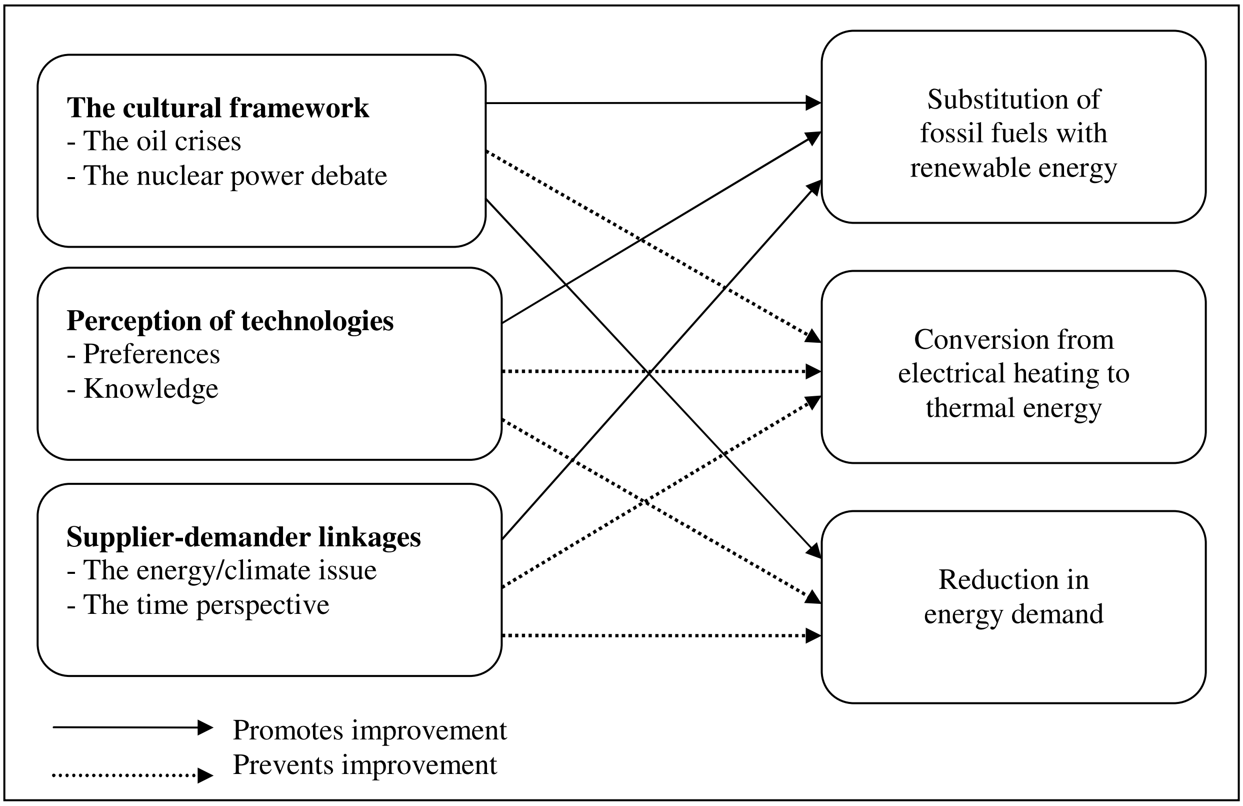


Figure 5.2 summarizes the influence of institutional factors on the energy performance of buildings from 2000 to 2006. These factors may be perceived as the central elements of the path dependency which have differing implications for diffusion of the technologies. Institutional factors have both promoted and prevented the improvement of energy performance of buildings during the period under study. These factors are inter-

linked, as the cultural context influences values, preferences and perceptions.

The substitution of fossil fuels with renewable energy has been promoted by the focus on energy security and global warming. These issues have also influenced perceptions of oil, which again are integrated in the values and norms of suppliers and demanders. Thus, we see that all the institutional factors promote the substitution of fossil fuels with renewable energy. This is also in line with the empirical findings that reveal a significant amount of substitution during the period under study.

The very low CO_2 emissions from electricity production, the perception of electrical heating, and supplier-demander linkages have acted against the conversion from electrical heating to thermal energy. In other words, all the institutional factors have inhibited change in this area. Technological change that is in conflict with institutional factors is likely to be slow and incremental. The empirical findings support this, as we find a minor increase in electrical heating during the period studied.

The reduction in energy demand is promoted by the cultural context, but prevented by perception of technologies and supplier-user linkages. This implies that the current path dependency promotes energy efficiency to some degree, but a regime shift that could significantly reduce energy demand is prevented by both the perception of technologies and supplier-demander linkages. The increased attention to climate change in 2006 may have broken this path-dependency, but this event occurred too recently to affect the energy performance of buildings in the period 2000 to 2006.

5.4 The regulative approach

The regulative approach stresses the influence of formal rules and laws on the improvement of energy performance of buildings. Regulations and economic measures are important to ensure that measures that will lead to the attainment of policy goals are carried out, even if they are not cost-efficient or for other reasons are not the first choice among suppliers and consumers. Conversely, the lack of such instruments may prevent the use of technologies that are crucial for improving the energy performance of buildings. Three regulative factors will be discussed here: policy goals, regulations, and economic measures.

5.4.1 Policy goals

Policy goals can be perceived as the formalization of institutions, as they are a manifestation of the majority's norms and values. These goals form the starting point for the policy instruments discussed in the following sections. A better understanding of pressing policy goals related to energy use in buildings may help to reveal how they affect the elements of energy performance of buildings.

Policy goals have different implications for the three elements of energy performance of buildings, and it is the same emphasis as was shown in the cultural context. It is the substitution of fossil fuels with renewable energy sources and energy efficiency that are mentioned in goal formulations – both the goals from 2001 and the revised ones of 2006. After the reformulation in 2006, the goals for fossil fuels and energy efficiency were formulated in terms of accurate measures for reduction, while the target for renewable energy sources is still vague. Setting exact measures for the goals has also made them more ambitious. The use of measures in policy goals may yield more goal-directed policy than vague formulations. The evaluation of the policy may also become more accurate. As these goals were revised in 2006 it is not likely that they have had any effect as yet. However, they illustrate the strong political emphasis on reduction in fossil fuels and on energy efficiency.

For reducing the reliance on electrical heating, there are still no clearly defined goals. The main focus is on energy efficiency and renewable energy versus fossil fuels. This is also in line with our empirical findings, as we have noted a substitution of fossil fuels with renewable energy and a reduction in energy use, but not a conversion from electrical heating to thermal energy. Converting from electrical heating to thermal energy has been an important objective (interview), but as long as this is not made specific in goal formulations, the focus here is substantially lower than with the two other elements. However, if energy carriers are weighted, the conversion from electrical heating may be incorporated into the goals.

Thus we see that, although policy goals promote the substitution of fossil fuels with renewable energy and reduction in energy demand, they act to inhibit the conversion from electrical heating to thermal energy, as this has not been made an explicit goal.

5.4.2 Regulations

Regulations are perhaps the most effective policy instrument, as they mandate specific behaviours. However, as Scott (2001) stresses, making the rules is not enough: monitoring adherence, and the use of sanctions if they are not followed, are also important elements. Building regulations are the most important regulations that affect energy performance. They have primarily affected energy demand, as there are no requirements as to choice of heating system or energy carrier.

It is widely believed that building regulations apply only to new buildings (interviews). However, there are also requirements for existing buildings, but, according to one interviewee, the law is not followed when doing renovations. The reason is twofold: the law is unclear, and the municipalities do not follow it up. The requirements for energy efficiency can be imposed only on measures that lead to changes in the building, but the current regulations do not specify or define what is considered as a ‘change’ in a building (Ministry of Sustainable Development 2005). The possibility for imposing requirements on the existing building stock is available, but it is not practised. Measures to reduce energy demand in the existing building stock are of great importance, as such structures will constitute the majority Sweden’s building stock well into the future . The need for more accurate definitions is also recognized in the government bill from 2005, and the National Board of Housing, Building and Planning is currently working on new regulations for the existing building stock (interview).

Building regulations may have varying formulations for measuring the energy demand of a building. While the former regulations had requirements for energy loss through requirements for non-leakage and insulation (interview), the requirements of the new building regulations that came into force in July 2006 are formulated in terms of energy delivered to the building (National Board of Housing, Building and Planning 2006). The use of delivered energy as a measure allows for more free play, and thinner insulation may be compensated for by energy-efficient windows. The focus is the result, not how this is achieved. However, as it is the energy delivered that is used as a measure for energy demand, heat pumps may be used to lower the use for delivered energy, even though actual energy use will be higher. The motivation for using the output – in this case, delivered energy – as a standard, is that such requirements do not demand the use of a specific technology (Christiansen 2001). However, using delivered energy as a measure for the energy demand of a building gives advantages to technologies like heat pumps and solar collectors, as they exploit energy from the surroundings and this is not calculated in the energy statistics. The result is that the building regulations in practice influence the choice of technology: 'It is not longer possible to connect one- and two-family houses to district heating. You have to use heat pumps.' (interview)

> It should be the same whether you get the energy from inside or outside the building. All losses should be included in all links. That is what is wrong with the current building regulations. (interview)

Some claim that weighting the delivered energy may compensate for this (Swedish Heat Pump Association and Swedish District Heating Association in Ministry of Sustainable Development 2005).

The implications of the new building regulations are in line with our empirical findings, as sales of heat pumps have increased significantly during the period. However, these regulations are unlikely to have had any impact on energy performance during the period under study, due to their recent implementation. But the differences in how to formulate the requirements and measures for energy demand of a building illustrate how regulations can be used both for promoting and for preventing the improvement of energy performance of buildings. Even though new buildings represent a very small portion of the total building stock, they will continue to stand for many years to come, so technological choices made in the course of planning, designing and construction will influence the possibilities for improving energy performance in the long term. The construction of new buildings provides the most opportunities for improving energy performance, as also technological change on the system level is possible. Hence, stricter building regulations for new buildings may have a significant influence of the energy performance of buildings in the long term. There are some disagreements of the importance of the building regulations. According to one interviewee, building regulations are not a driving force, as it is possible to construct buildings that use significantly less energy. The way the current regulations are formulated, it is possible to build as previously, and simply install a heat pump to satisfy the requirements for delivered energy. On the other hand, strict regulations may speed up the reduction in energy demand (interview).

According to Kemp (2000) the use of bans is important for achieving radical technological change. A ban against direct electrical heating in new buildings in Sweden was discussed in the government bill in 2001. The National Board of Housing, Building and Planning made a report on the potential consequences, but concluded that a ban would have high socio-economic costs but lead to only a minor reduction in electricity use due to the low number of new buildings that have direct electrical heating (National Board of Housing, Building and Planning 2003b). For buildings with very low energy use due to energy-efficient building techniques, direct electrical heating is a cost-efficient alternative (Ministry of Sustainable Development 2005). Thus, instead of a ban, the government opted for stricter requirements for energy use for one- and two-family houses with direct electrical heating as their main heating source, and financial support for converting from direct electrical heating to other energy technologies. As noted earlier, the choice of heating system creates important framework conditions that influence the possibilities for improving energy performance in the future. Direct electrical heating is not very flexible and may create lock-in in the long term, as it is expensive and requires extensive work to change to a waterborne heating system.

Regulations have therefore first and foremost acted to inhibit the change from electrical heating to thermal energy due to the lack of a ban and the new formulation of requirements. They also work counter to a reduction in energy demand, as building regulations are in practice not applied to existing buildings.

5.4.3 Economic measures

Sweden has had a long tradition of using economic measures as an instrument for moulding behaviour to meet policy goals. The various economic measures may be divided into two groups: general taxes and duties, and support directed towards specific technologies. These measures are directed towards all the three elements of energy performance of buildings, as shown in Table 4.2.

According to several interviewees, taxes have been the most important measure for the substitution of fossil fuels with renewable energy. Taxes are used to adjust the prices on energy carriers to give incentives for using renewable and thermal energy. The CO_2 tax is seen as the chief measure for promoting the use of bio-energy and district heating, as it makes exemptions for renewable energy carriers like bio-fuels (interviews). Sweden's carbon tax has increased during the period, thereby providing additional incentives for substituting fossil fuels with renewable energy carriers.

Also the tax on electricity used for heating has increased during the period, but our empirical findings indicate that it is still not high enough to compensate for the low investment costs of electrical heating in new buildings and the installation of air-to-air heat pumps in existing buildings. To hasten the conversion from electrical heating to thermal energy, this tax must be raised, so as to provide sufficient incentives.

Support arrangements for investment are important for technologies that have a long payback time or are not profitable. Support for installing solar collectors was introduced in 2000 – and in that year, sales doubled (Ministry of Enterprise, Energy and Communications 2007:5). This support has made solar collectors competitive and may help to explain the significant increase in solar collector systems sold from 2000 to 2006 (interview). There has also been a support arrangement for changing from oil to district heating or rock/ground/water heat pumps in one- and two-family houses. However, a report from the Energy Markets Inspectorate (2007) concludes that support arrangements for substituting oil with renewable energy have had only minor effects, as the oil-based systems would have had to be replaced anyway due to the high age of the boilers. Things have merely been speeded up.

There is also support for converting from direct electrical heating to thermal energy. The Energy Market Inspectorate (2007) is more positive to this arrangement than the former, because such conversion is very expensive, as a waterborne heating system is necessary. All the same, the support may be too low to compensate for the high costs of installing a waterborne heating system (Energy Market Inspectorate 2007).

There is some scepticism to support arrangements of this type, as they favour specific technologies at the expense of others (interview). Even the branches that promote the use of the technologies that benefit from these arrangements are sceptical (Energy Markets Inspectorate 2006). The use of general taxes seems preferable to support for specific technologies because support arrangements may cause unfair competition, giving benefits to some technologies at the expense of others. With a system of general taxes, it is up to the market to decide which technologies to use (interview). However, as the support arrangement for solar collectors has shown, such support may be vital to ensure the diffusion of less-known technologies involving high investments. A long-term support policy may be crucial if the goal is to establish the technologies and create the foundations for further growth in the future. Otherwise, the market may become too unpredictable: volumes will continue to increase as long as the support exists, but once the support is withdrawn the suppliers will sit there with leftover capacity (interview).

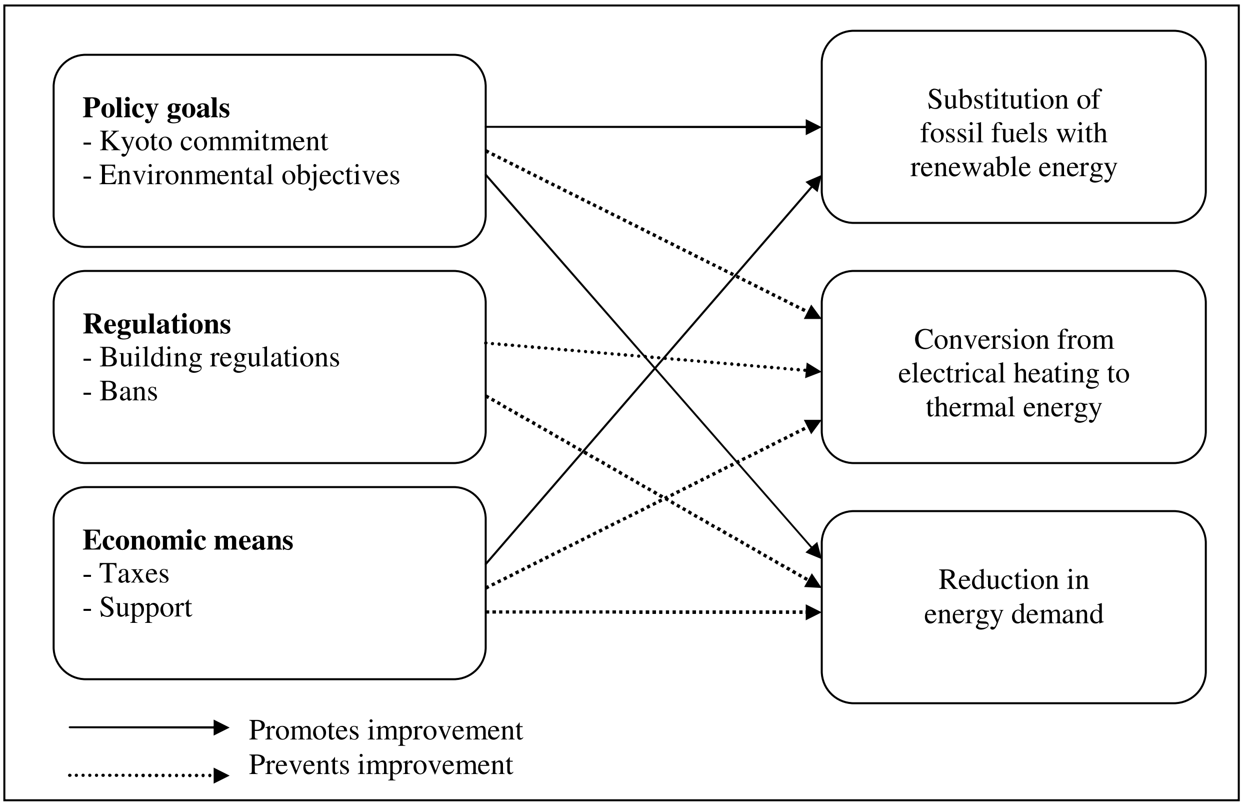
Support arrangements for energy-efficiency measures may be important for reducing energy use in existing buildings. However, support for such measures is currently limited, which may have worked against a reduction in energy demand. The 'million programme' houses are now in need of renovation. Swedish Housing companies have asked for support for renovating these houses, but they are left to pay the bill themselves (interview). Renovation of these buildings will have a long-term effect due to large number and the considerable extent of the renovations necessary because of the poor present condition of these structures. It is possible to reduce energy demand significantly with thicker insulation and energy-efficient windows, and even more by applying passive house standards. The lack of policy instruments directed to ensuring the energy-efficient renovation of these buildings may prevent improvements in their energy performance. Building regulations would be the most efficient instrument if the requirements for energy demand also had been applied to renovations of existing buildings. Also support for energy-efficient renovations could promote the implementation of such measures.

Thus we see that economic measures have promoted the substitution from fossil fuels with renewable energy as the prices on the energy carriers have been altered in favour of renewable alternatives. With higher taxes, the substitution rate might also have been higher. This is especially the case for the tax on electricity used for heating: this tax is too low to compensate for the lower investment costs for electrical heating. Also the lack of sufficient support arrangements works against the conversion from electrical heating to thermal energy and reduction in energy demand.

5.4.4 Summary of regulative factors

Figure 5.3 summarizes our discussion on the implications of regulative factors on the development of energy performance of buildings from 2000 to 2006. Both policy goals and taxes have promoted the substitution of fossil fuels with renewable energy. Whereas support arrangements are limited to a minority of the buildings, taxes apply for all and give the best effects on aggregate level.

Figure 5.3: Influence of regulative factors on the improvement of energy performance of buildings, 2000-2006



Converting from electrical heating to thermal energy is inhibited by all the factors. There are no policy goals directed towards this end, and existing taxes and support arrangements are too low to outweigh the low investment costs of installing electrical heating in new buildings and the high costs of changing to a waterborne heating system in existing buildings. The change from electrical heating could be speeded up by a ban on direct electrical heating in new buildings, but this has not been politically acceptable. The new building regulations will prevent the conversion further, because using delivered energy as a measure of energy demand will promote the use of heat pumps.

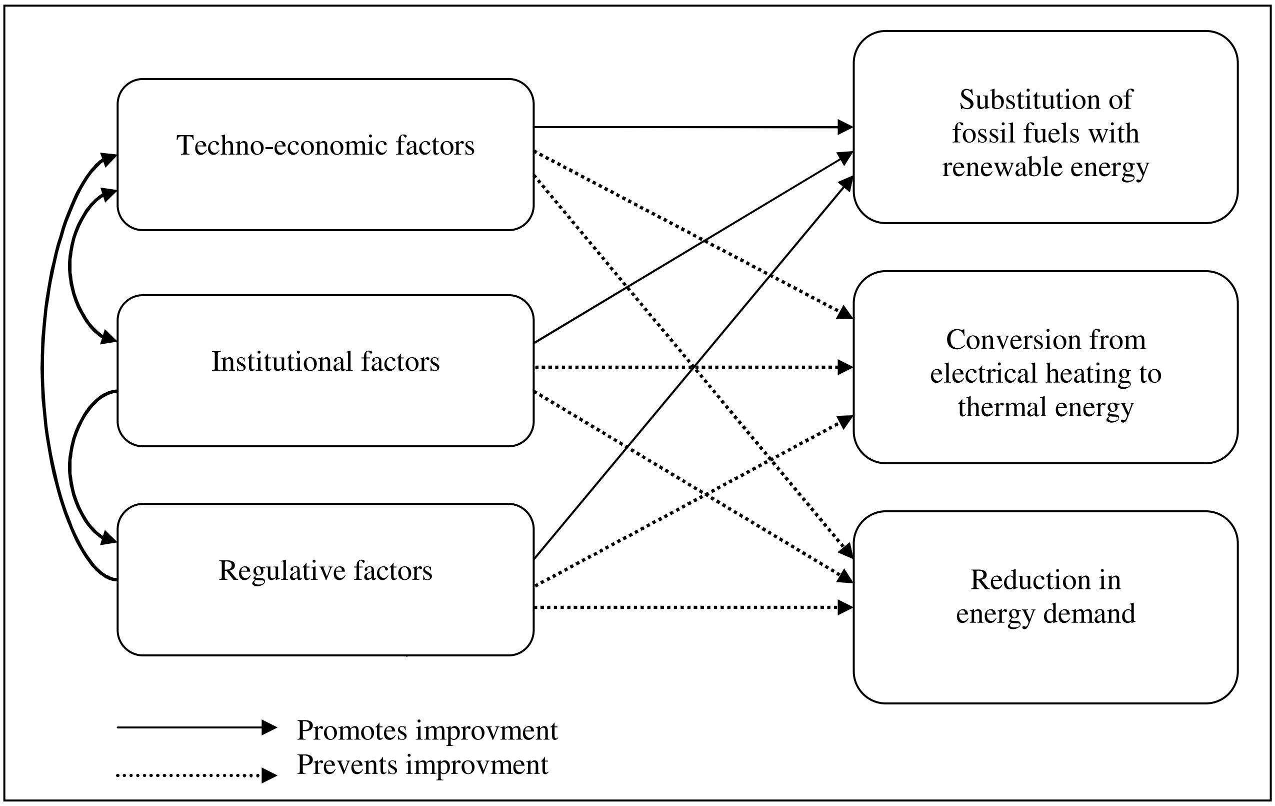
Reduction in energy demand is promoted by the policy goals, but prevented by the regulations and economic measures. Building regulations are the most important measure to reduce the energy demand of buildings. The objective of these regulations is to ensure that energy demand does not exceed a certain limit. However, it is possible to construct new houses with a significantly lower energy demand than the building regulations require. In that sense, the building regulations may be characterized as 'technological freezing' as they do not provide incentives to go further than what is required. Because they are not applied to existing buildings, the effect of the regulations is further limited. Reduction in energy demand is also prevented by the lack of support for energy-efficient renovations.

5.5 Co-existence and mutual influence of the three approaches

Figure 5.4 summarizes our empirical findings and analysis. All the factors have promoted the substitution of fossil fuels with renewable energy. This is also in line with our empirical findings, as substitution has clearly increased during the period under study. The existing technological system has been favourable and energy prices have promoted renewable energy technologies. In addition, the cultural context has also emphasized this substitution, which has again affected the regulative factors: policy goals, taxes and support arrangements to promote substitution. Of course, if all these factors had been stronger, the substitution could have been greater. Nearly one-fifth –19% – of the energy used for heating in Sweden still comes from fossil fuels, and complete substitution may require stronger pressure. The techno-economic factors are difficult to change, except for altering the prices on energy carriers and technologies to promote higher rates of substitution. This may be done by increasing taxes, and the influence of regulative factors on the technological ones is shown with an arrow in Figure 5.4. Hence, it is the institutional and regulative factors that are most important for increasing the rate of substitution.

Converting from electrical heating to thermal energy is inhibited by all the factors. As discussed earlier, the existing technological system creates certain framework conditions for the possibilities for improving the energy performance of buildings. In particular, these factors obstruct the possibilities for converting from electrical heating to thermal energy. The technological context, the high share of nuclear power and low share of fossil fuels in electricity production all influence the institutional factors and the perception of electrical heating. However, the institutional factors influence the development of the existing technological system which will form the technological context in the future. Institutional factors also influence the regulative factors: the policy goals and the instruments. The mutual influence of the various explanatory approaches means that all factors work against the conversion from electrical heating to thermal energy. The Swedish cultural context has influenced the shaping of the existing technological system, which again affects perceptions of technologies and supplier-demander linkages, and spreads further to the regulative factors.

Figure 5.4: Factors promoting and preventing the improvement of energy performance of buildings in Sweden, 2000-2006



For reducing energy demand, the existing technological system sets certain limits in the existing building stock. However, the renovation of houses to passive house standard shows that it is possible to achieve significant reduction in energy demand also in the existing building stock. But as the alteration of existing buildings demands sizeable investments, the long payback time prevents such measures from being carried out. Despite the scepticism towards passive houses and the low emphasis on energy efficiency among demanders and suppliers, reduction in energy demand has now become integrated in the cultural context. Also the institutional and regulative factors have promoted reduced energy demand. The Swedish cultural context has influenced such regulative factors as policy goals, energy taxes, support arrangements and building regulations. Building regulations have been important for reducing the energy demand, but the new ones from 2006 will act against this. As the new and old building regulations existed side by side in 2006, it is not likely that they have prevented reduced energy demand in the period studied. Still I have chosen to assess the influence of the regulative factors as inhibiting a reduction of energy demand. This is due to the existence of building regulations that set requirements for energy demand when alterations are made to existing buildings. As measures in the existing building stock are very important for improving the energy performance on an aggregate level, the non-application of these regulations is an important barrier for reducing energy demand.

However, our empirical mapping shows that energy use in buildings has been reduced during the period under study. There may be several reasons why this has happened despite the various barriers discussed above. One reason can be found in the difference between delivered energy and energy demand. The significant increase in the use of heat pumps during the period can explain some of the reduction in delivered energy, as heat pumps have no effect on energy demand, but reduce the need for delivered energy by two-thirds. This corresponds with the fact that almost all heat pumps can be found in one- and two-family houses – the type of building that has also had the greatest reduction in energy use. In addition delivered energy is not only a result of energy demand, but is also influenced by the behaviour of the people living in the buildings. Another explanation may be that while all the factors act to prevent a radical reduction in energy demand, they do promote incremental improvements.

Our discussion of the mutual influence of the technological, institutional and regulative factors has emphasized the importance of technological trajectories and path-dependency for technological change. These two concepts are interlinked, and work to prevent changes outside the established trajectory or path. According to Rosenkopf and Tushman (1994) it is not the techno-economic factors that determine the choice among several alternatives, but institutional factors. For improving the energy performance of buildings, techno-economic factors have proved to have significant importance, both as barriers and as driving forces. However, as noted earlier, there is still a considerable potential for improving energy performance within the existing technological regime, following the current trajectory and path. If there is to be widespread use of passive house principles in new constructions and in renovations, however, this will require the development of a new technological trajectory and path.

5.6 Summary of the analysis

The analysis has discussed the influence of each of the explanatory approaches and how these have influenced and strengthened each other. The technological, institutional and regulative factors have been found to promote as well as prevent improvements in energy performance. The substitution of fossil fuels with renewable energy is promoted by all the factors, while the conversion from electrical heating is prevented by all of them. This is also in line with our empirical findings: the substitution of fossil fuels with renewable energy has been improved most, while the use of electrical heating has increased. On the other hand, energy use has decreased in spite of the various techno-economic, the institutional and the regulative barriers.

6 Conclusion

My motivation for studying energy use in buildings was that buildings are responsible for a significant proportion of total energy use and climate gas emissions. Already there exist a wide range of technologies that may improve the energy performance of buildings. However, the mere existence of a technology is not sufficient for it to be used: and many different factors influence the possibilities for improving energy performance. Sweden's building sector was chosen as a case to explore these factors. The background for studying the energy performance of Swedish buildings was the interesting context provided by the mixed energy structure and ambitious climate goals.

This report has aimed at studying the development of energy performance of Swedish buildings from 2000 to 2006. The first research question focused on characterizing this development, while the second research question inquired into the factors that had acted to promote or prevent improved energy performance of buildings during the period under study.

6.1 Characterization of the development of energy performance

The report has used a threefold understanding of energy performance of buildings, stressing the substitution of fossil fuels with renewable energy, the conversion from electrical heating to thermal energy, and reduction in energy demand. Our empirical findings show that there has been a substitution of fossil fuels with renewable energy and a reduction in energy use – but not a conversion from electrical heating to thermal energy. One- and two-family houses have had the most significant improvement for substitution and reduction, while multi-family structures are the only type of building to have converting from electrical heating to thermal energy. Non-residential buildings have a similar energy structure and improvement as multi-family houses, but have had a small increase in electricity used for heating.

The diffusion of technologies that affect the development of energy performance of buildings has been categorized as changes at component versus changes at system level. Changes at component level are understood as the substitution from one energy technology to another, while changes at system level demand switching of heating systems. Two different heating systems exist within the current technological regime, direct electrical heating and waterborne heating systems. However, a third heating system has been introduced in Sweden under the period of study: the passive house concept. By applying specific principles for constructing and renovating buildings the energy demand is reduced to a minimum and none of the two traditional heating systems are required.

The substitution of fossil fuels with renewable energy requires changes only at the component level like the changeover from an oil boiler to a pellets boiler or district heating. This is because buildings that substitute from oil to other energy carriers already have a waterborne heating system. Hence, changes at system level are not necessary. Theories of technological change states that changes at component level are perceived as less fundamental and are most easy to implement (Unruh 2002). This is supported by the empirical findings as the greatest improvement of energy performance under the period of study has been on component level for substituting fossil fuels with renewables. Depending on the existing heating system, the conversion from electrical heating may on the other hand also demand changes at system level. For buildings with waterborne electrical heating changes at component level is sufficient, e.g. from an electrical boiler to a pellets boiler. However, buildings that have direct electrical heating the options for improving the energy performance on component level are limited. It is possible to install air-to-air heat pumps, but this will only reduce the electricity use by 15-30% (Johansson et al. 2005:1390). For achieving a completely conversion a waterborne heating system must be installed. Also reduction in energy demand may be achieved by both changes at system level and component level. Components like energy efficient windows and insulation will reduce the energy demand to some degree, while system changes by applying passive house principles will give significantly better improvement. However, changes at system level are perceived as more fundamental and are more difficult to implement according to Unruh (2002). This is in line with the empirical findings as there has not been a conversion from electrical heating to thermal energy and only a few passive houses have been constructed from 2000-2006.

The two heating systems that co-exist within the current technological regime – direct electrical heating and waterborne heating systems – have very different potentials for improving energy performance. Whereas waterborne heating systems allow the use of all renewable and thermal energy carriers, direct electrical heating locks energy use to electricity. On the other hand, the improvements gained by applying the passive house concept far exceed the benefits involved in improving existing heating systems. In spite of the few passive houses constructed from 2000-2006, the introduction of the first passive houses in Sweden represents a new technological regime as this is a radical new way of constructing buildings. However, the empirical findings reveal that improvement in energy performance during the period under study has mainly taken place within the existing technological regime, and can be perceived as a continuation of earlier trends.

6.2 The explanatory approaches

Three different explanatory approaches have been derived from theories of institutions and technological change: techno-economic, institutional and regulative. These approaches have been used to explore driving forces and barriers to improved energy performance of buildings in Sweden from 2000 to 2006. They stress different factors as important for achieving technological change and constitute therefore a broad basis for analysing energy performance of buildings. By first discussing the approaches separately and then their mutual influence and co-existence, the report has sought to provide an overall understanding of the complex technological system of energy performance of buildings.

The techno-economic approach focuses on the inherent attributes of the existing technological system and the technologies that affect energy performance of buildings. The key to understanding the diffusion of technologies may lie in the technologies themselves and how these attributes match the physical infrastructure provided in the technological system. Three factors have been explored: physical infrastructure, attributes of the technologies, and prices and costs. The physical infrastructure is the result of previous technological development and constitutes an important framework for technological change. Both the existing heating systems and how the buildings are constructed (e.g. insulation and tightness) give different possibilities for improving the energy performance. Also the importance of building type has been discussed. The analysis concludes that type of building is affecting the opportunities for reducing the energy demand as multi-family structures have a significant lower energy use per dwelling then one- and two-family houses. One important attribute that differ among the technologies is energy input. Whereas solar collectors and bio energy are completely run by renewable energy, fossil fuels are energy input in district heating systems and electricity production. Even though there has been a substitution from fossil fuels with renewable energy in the district heating production, still 16% fossil fuels remain. Energy input in heat pumps may also prevent improved energy performance as electricity is needed to extract the heat from the surroundings. If heat pumps replace oil the electricity used for heating will increase, while it will decrease if the former energy carrier was electricity. Prices and costs for energy carriers and technologies differ significantly and favours renewable energy. However, the low investments for electrical heating make this an attractive heating alternative, especially for buildings with low heating demand. The conclusion of the influence of the techno-economic factors is that they have pulled in the same direction, working to promote the substitution of fossil fuels with renewable energy, while acting against the conversion from electrical heating to thermal energy and against a reduction in energy demand.

The institutional approach stresses that the importance of norms, values, cognition and culture for technological change. Such factors are especially important for complex technological systems like that studied in this report. Institutional factors explored here are the Swedish cultural context, perception of technologies, and supplier–demander linkages. The Swedish cultural context has developed over time and given different meanings to energy performance of buildings. Two important issues that have had influenced the motivations for improving the energy performance are decommissioning of nuclear power and climate change. The concern for global warming has first and foremost had implications for the use of fossil fuels, but also led to increased acceptance for nuclear power and electrical heating. Hence, the cultural framework has influenced the perception of technologies. There are scepticism against some of the renewable technologies like solar collectors and district heating, but as several other alternatives to fossil fuels exist this is not preventing the substitution from fossil fuels. However, the increased acceptance for electrical heating and absence of focus on energy quality is a barrier to conversion from electrical heating to thermal energy. The exploration of the last institutional factor, supplier-demander linkages reveals that neither the suppliers nor the demanders have had any special interest in energy performance. Due to high demand for buildings and lack of common standards to calculate cost in a long-term perspective, improved energy performance is prevented. Our analysis concludes that while the Swedish cultural context have promoted substitution of fossil fuels with renewable energy, has converting from electrical heating to thermal energy been inhibited by all three factors. Reduction in energy demand is promoted by the cultural context, but prevented by the two other factors.

The regulative approach stresses how formal rules and laws affect the energy performance of buildings. This approach both includes the formal goals and the policy instruments that shall effect social change to attain these goals. Three regulative factors have been identified in this study: policy goals, regulations, and economic measures. While there are concrete and ambitious goals for reduced use of fossil fuels and increased energy efficiency, there are no specific goals for conversion from electrical heating to thermal energy. The lack of the latter indicates that the use of electricity for heating is not perceived as a major problem. At the same time are the energy taxes on electrical heating and the support arrangements for conversion from electrical heating to thermal energy not sufficient to compensate for the lower investment costs for electrical heating. For the substitution of fossil fuels with renewable energy the carbon tax on fossil fuels have been important as the price on energy carriers have been altered to favour renewables. Support arrangements have also been favourable, especially for less diffused technologies like solar collectors. The building regulations are first and foremost affecting the energy demand of buildings. However, they are only applied on new buildings even though requirements for altering existing buildings also exist. In addition, as it is possible to construct buildings with significant lower energy use then what is required, the current regulations are preventing a radical reduction in energy demand. Hence, we find that policy goals and economic measures have promoted the substitution of fossil fuels with renewable energy. Also here, all the factors have worked against the conversion from electrical heating to thermal energy, while reduction in energy demand is promoted by the policy goals but prevented by regulations and economic measures.

The techno-economic, institutional and regulative factors have had a mutual influence on each other, and the effects have spread from the techno-economic factors to the institutional and further to the regulative and thus become reinforced. Technological trajectories and path-dependency are interlinked and promote the same development: a radical substitution of fossil fuels with renewable energy, incremental reduction in energy demand, and against conversion from electrical heating to thermal energy.

6.3 Theory implications and the need for further research

By applying three explanatory approaches and separating the factors that influence the development of energy performance of buildings, the analysis has provided a clearer view of the driving forces and barriers to the diffusion of relevant technologies. Understanding the factors that influence technological change is important for understanding a complex technological system as the one of energy performance of buildings. The contextualization of technological change is important for an in-depth study of the complex factors that influence the diffusion of technologies. Technological capability is an important element in this context and is influenced by both the physical infrastructure and the specific attributes of the technologies in question. Our analysis has revealed that especially the physical infrastructure and the attributes of the technologies may lock in some technologies and lock out others. These physical factors are more difficult to alter than prices and costs, as they can be affected by, for example, taxes and support arrangements. While the techno-economic and the regulative factors are more definite as they are materialized through physical objects and structures and written laws and regulations, the institutional factors are the cognitive and normative systems that determine our perceptions and interpretations. However, though they are more difficult to uncover, such institutions are significant as they influence the techno-economic physical structures as well as the written regulative elements.

The report thus gives support to the considerable emphasis on institutions in theories of technological change. It is not first and foremost the techno-economic factors that prevent the improvement of energy performance, as there exists several cost-efficient technologies that may improve the energy performance of buildings significantly. The perception of problems and solutions are essential to the selection of technologies. The institutional approach stresses that what is technologically *possible* to do may be completely different from what is considered *worthwhile* to do. These factors are crucial for technologies that require a radical change to gain ground. Technological change that conflicts with established institutional factors, like converting from electrical heating to thermal energy, requires changes in these institutions in order to achieve improvement. While the techno-economic factors are difficult to change both in short and the long term due to the long lifetime of buildings, there are better possibilities for changing the institutional and regulative factors. However, this is by no means an easy process. Nevertheless, it is still necessary.

In the process of examining the field of energy performance of buildings and writing this report, several related issues have emerged. One important question is how much of the energy use of building depends on the energy performance of the building itself and how much depends on the behaviour of the people who live there. Exploring this relationship has been beyond the scope of the current report, but may be both theoretically and empirically important.

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Appendix 1: Interviewees

- Martin Storm, National Board of Housing, Building and Planning, Karlskrona, 24 October 2007
- Lars Anden, Solar Energy Association of Sweden, Falkenberg, 23 October 2007
- Kent Nyström, Swedish Bioenergy Association (Svebio), Stockholm, 16 November 2007
- Peter Roots, Swedish Heat Pump Association (Svep), Stockholm, 12 November 2007
- Åke Skarendah, CERBOF, Stockholm, 13 November 2007
- Danielle Freilich, Swedish Construction Federation (BI), Stockholm, 13 November 2007
- Mikael Gustafsson, District Heating Association, Stockholm, 16 November 2007
- Michael Rantil, Swedish Energy Agency, Stockholm, 13 November 2007
- Per Lilliehorn, The Energy Alliance, Stockholm, 15 November 2007

Appendix 2: Interview guide

Introductory questions
- Could you please start by telling about your background, your role and your work?
- Could you briefly tell about the development of energy use of buildings in Sweden?

Energy policy
- Is improving the energy performance of buildings an important policy goal? How is this expressed?
- In what way does energy policy promote the use of technologies that improve the energy performance of buildings?
- In what way does energy policy prevent the use of technologies that improve the energy performance of buildings?
- Which policy instruments do you think are necessary but have not been used?
- Which economic measures have been important and in what way? Which are lacking/are too weak?
- Which regulations have been important and in what way? Which are lacking/should be stricter?

Techno-economic factors
- Which are the most important technological barriers?
- What are the advantages of technologies that promote the energy performance of buildings?
- Are any of the technologies better/worse than others?
- Can the technologies satisfy the needs of the users?
- What are the most important economic barriers to their being used?
- What changes are required? Is the demander or the supplier side more important?

Institutional factors
- What are the most important attitudes among (politicians, building companies, users)?
- What conflicts of interest conflicts exist?
- Have there been any changes in values or preferences?
- What are the attitudes towards nuclear power today, and how does this affect the thinking on energy performance of buildings?
- Are any of the technologies more/less accepted than others?
- What are the motivations for improving energy performance? (energy security, economy, climate change)
- Have any actors been more important than others?

Concluding questions
- What would you identify as the most important barrier to improved energy performance of buildings?
- What would you identify as the most important driving force behind improved energy performance of buildings?
- Is there anything you would like to add?

Appendix 3: Renewable and fossil share of energy used for heating[23]

Renewable share of energy used for heating buildings, 2000

Share of renewable energy of total electricity production:[24]
(water power 77.8 TWh + wind power 0.5 TWh + bio-energy 4.913) / (total net production 142 TWh) = 0.59 ►59%

Share of renewable energy of total district heating production[25] (bio-energy 23.8 TWh + heat pump 4.4 TWh x 0.59 + electrical boilers 1.2 TWh x 0.59 + waste heat 4.6 TWH) / (total energy input for district heating = 55.4) =0.74 ►74%

	One- and two-family houses	**Multi-family structures**	**Non-residential buildings**	**Total**
Bio-energy[26]	9.7 TWH	0 TWH	0 TWH	9.7 TWh

Total district heating	2.7 TWh	21.5 TWh	14.9 TWh	39.10 TWh
Renewable share	74%	74%	74%	74%
Total renewable district heating	1.998 TWh	15.91 TWh	11.026 TWh	28.93 TWh

Total electricity	14.9 TWh	1.8 TWh	3.9 TWh	20.6 TWh
Renewable share	59%	59%	59%	59%
Total renewable electricity	8.791 TWh	1.062 TWh	2.301 TWh	12.15 TWh

Total renewable	20.5 TWh	17.0 TWh	13.3 TWh	50.8 TWh
Total energy used for heating	39.9 TWh	27 TWh	23.7 TWh	90.6 TWh
Renewable share of total energy used for heating	**51%**	**63%**	**56%**	**56%**

[23] The calculations have been done using the same method as National Board of Housing, Building and Planning (2007)
[24] Swedish Energy Agency 2007a:20-21
[25] Swedish Energy Agency 2007a:24-25
[26] The rest of the figures: Swedish Energy Agency and SCB 2003a:2 and 2007a:2

Fossil share of energy used for heating buildings, 2000

Share of fossil fuels of total electricity production
(oil 3.3 TWh + natural gas 0.5 TWh + LPG 0.3 TWH + Coal 3.7 TWh) / (total net production 142 TWh) = 0.05 ►5%

Share of fossil fuels of totally district heating production
(oil 30 TWh + natural gas 2.5 TWh + coal 2.4 TWh + heat pumps 0.4 TWH x 0.05 + electrical boilers 0.1 x 0.05) / (total energy input for district heating = 55.4)=0.18 ►18%

	One- and two-family houses	**Multi-family structures**	**Non-residential buildings**	**Total**
Oil	12.3 TWh	3.4 TWh	4.6 TWh	20.3 TWh
Natural gas	0.3 TWh	0.3 TWh	0.3 TWh	0.9 TWh

Total district heating	2.7 TWh	21.5 TWh	14.9 TWh	39.10 TWh
Fossil share	18%	18%	18%	18%
Total fossil district heating	0.486 TWh	3.87 TWh	2.682 TWh	7.04 TWh

Total electricity use	14.9 TWh	1.8 TWh	3.9 TWh	20.6 TWh
Fossil share	5%	5%	5%	5%
Total fossil electricity	0.745 TWh	0.09 TWh	0.195 TWh	1.0 TWh

Total fossil fuels	13.8 TWh	7.7 TWh	7.8 TWh	29.3 TWh
Total energy for heating	39.9 TWh	27 TWh	23.7 TWh	90.6 TWh
Fossil share of total energy used for heating	**35%**	**28%**	**33%**	**32%**

Renewable share of energy used for heating buildings, 2006

Share of renewable energy of total electricity production
(hydropower 61.2 TWh + wind power 1 TWh + bio-energy 10.87)/(total net production 140.1 TWh) = 0.52 ►52%

Share of renewable energy of total district heating production
(bio-energy 36.2 TWh + heat pump 2.9 TWh x 0.59 + electrical boilers 0.2 TWh x 0.52 + waste heat 4.6 TWH) / (total energy input for district heating = 55.4) =0.79 ►79%

	One- and two-family houses	**Multi-family structures**	**Non-residential buildings**	**Total**
Bio-energy	8.8 TWh	0.2 TWh	0.5 TWh	9.5 TWh

Total district heating	4.7 TWh	22.4 TWh	14.7 TWh	41.8 TWh
Renewable share	79%	79%	79%	79%
Total renewable district heating	3.713 TWh	17.70 TWh	11.61 TWh	33.022 TWh

Total elelctricity	15.3 TWh	1.5 TWh	3.9 TWh	20.7 TWh
Renewable share	52%	52%	52%	52%
Total renewable electricity	7.956 TWh	0.78 TWh	2.028 TWh	10.764 TWh

Total renewable	20.5 TWh	18.7 TWh	14.1 TWh	53.286 TWh
Total energy use for heating	32.4 TWh	26.1 TWh	21.2 TWh	79.7 TWh
Renewable share of total energy used for heating	**63%**	**72%**	**67%**	**67%**

Fossil share of energy used for heating buildings, 2006

Share of fossil fuels of total electricity production
(oil 2.5 TWh + natural gas 0.9 TWh + coal 3.7 TWh)/(total net production 140.1 TWh) = 0.05 ►5%

Share of fossil fuels of total district heating production
(oil 3.2 TWh + natural gas 2.2 TWh + coal 3.4 TWh) / (total energy input for district heating = 55.4) =0.16 ►16%

	One- and two-family houses	**Multi-family structures**	**Non-residential buildings**	**Total**
Oil	3.4 TWh	1.5 TWh	1.6 TWh	6.5 TWh
Natural gas	0.3 TWh	0.3 TWh	0.4 TWh	1 TWh
Total district heating	4.7 TWh	22.4 TWh	14.7 TWh	41.8 TWh
Fossil share	16%	16%	16%	16%
Total fossil district heating	0.752 TWh	3.584 TWh	2.352 TWh	6.688 TWh
Total electricity use	15.3 TWh	1.5 TWh	3.9 TWh	20.7 TWh
Fossil share	5%	5%	5%	5%
Total fossil electricity	0.77 TWh	0.075 TWh	0.195 TWh	1.035 TWh
Total fossil fuels	5.2 TWh	5.5 TWh	4.5 TWh	15.223 TWh
Total energy used for heating	32.4 TWh	26.1 TWh	21.2 TWh	79.7 TWh
Fossil share of total energy used for heating	**16%**	**21%**	**21%**	**19%**

Appendix 4: Energy used for heating, by energy carrier and building type, TWh and percentages[27]

	One- and two-family houses		Multi-family structures		Non-residential buildings		Total	
	2000	2006	2000	2006	2000	2006	2000	2006
Bio-energy	9.7	8.8	0	0.2	0	0.5	9.7	9.5
Electrical heating	14.9	15.3	1.8	1.5	3.9	3.9	20.6	20.7
Oil	12.3	3.4	3.4	1.5	4.6	1.6	20.3	6.5
Natural gas	0.3	0.3	0.3	0.3	0.3	0.4	0.9	1
District heating	2.7	4.7	21.5	22.4	14.9	14.7	39.1	41.8
Total energy used for heating	39.9	32.4	27	26.1	23.7	21.2	90.6	79.5

	One- and two-family houses		Multi-family structures		Non-residential buildings		Total	
	2000	**2006**	**2000**	**2006**	**2000**	**2006**	**2000**	**2006**
Bio-energy	24%	27%	0%	1%	0%	2%	11%	12%
Electrical heating	37%	47%	7%	6%	16%	18%	23%	26%
Oil	31%	10%	13%	6%	19%	8%	22%	8%
Natural gas	1%	1%	1%	1%	1%	2%	1%	1%
District heating	7%	15%	80%	86%	63%	69%	43%	53%
Total energy used for heating	100%	100%	100%	99%	100%	100%	100%	100%

[27] Figures for 2000: Swedish Energy Agency and SCB 2003a:2, figures for 2006: Swedish Energy Agency and SCB 2007a:2

Appendix 5: Energy use per heated area and dwelling[28]

	2000	2006	Change
Total heated area, m²	**596 000 000**	**580 500 000**	-3%
One- and two-family houses	257 200 000	262 200 000	2%
Multi-family structures	168 400 000	163 100 000	-3%
Non-residential buildings	170 400 000	155 200 000	-9%
Total energy used for heating, kWh	**90 600 000 000**	**79 700 000 000**	-12%
One- and two-family houses	39 900 000 000	32 400 000 000	-19%
Multi-family structures	27 000 000 000	26 100 000 000	-3%
Non-residential buildings	23 700 000 000	21 200 000 000	-11%
kwh/m²/year	**152**	**137**	-10%
One- and two-family houses	155	124	-20%
Multi-family structures	160	160	0%
Non-residential buildings	139	137	-2%
Number of dwellings	**3 990 000**	**4 435 903**	11%
One- and two-family houses	1 568 000	2 018 093	29%
Multi-family structures	2 422 000	2 417 810	0%
Energy use per dwelling, kWh	**22707**	**17967**	-21%
One- and two-family houses	25446	16055	-37%
Multi-family structures	11148	10795	-3%

[28] Figures for 2000: Swedish Energy Agency and SCB 2002:15,16,17
Figures for 2006: Swedish Energy Agency and SCB 2007a:16,17,18

Appendix 6: Energy use in buildings constructed after 2000[29]

	Kwh/m2/year
One- and two-family houses	121
Multi-family structures	126
Non-residental buildings	122

	One- and two-family houses, number of houses	**Multi-family structures**, number of flats/units	**Non-residential buildings**, heated area, m^2
Electrical heating	21 000	-	300 000
Electrical heating and bio-energy	7 000	-	100 000
Only bio-energy	1 000	-	-
ground/sea/rock heat pump	3 000	-	-
ground/sea/rock heat pump and bio-energy	2 000	-	-
ground/sea/rock heat pump and bio-energy	1 000	-	-
District heating	5 000	36 000	2 800 000
Others	2 000	7 000	1 300 000
Natural gas	-	2 000	-
Total	42 000	45 000	4 500 000

	One- and two-family houses, number of houses	**Multi-family structures**, number of flats	**Non-residential buildings**, heated area
Direct electrical heating	5%	-	-
Waterborne electrical heating	45%	-	7%
Electrical heating and bio-energy	17%	-	2%
Only bio-energy	2%	-	-
ground/sea/rock heat pump	7%	-	-
ground/sea/rock heat pump and bio-energy	5%	-	-
ground/sea/rock heat pump and bio-energy	2%	-	-
District heating	12%	80%	62%
Others	5%	16%	29%
Natural gas	-	4%	-
Total	100%	100%	100%

[29] One- and two-family houses: Statens energimyndighet och SCB 2007b:11
Multi-family houses: Statens energimyndighet och SCB 2007c:12
Non-residential buildings: Statens energimyndighet och SCB 2007d:18

Appendix 7: Energy input for district heating, 1970, 2000, 2006, TWh [30]

	1970	2000	2006
Oil	14.3	2.9	3.2
Natural gas		2.5	2.2
Coal		2.4	3.2
Bio-fuels	0.3	23.8	36.2
Electrical boilers		2.1	0.3
Heat pumps		7.5	5.6
Waste heat		4.6	4.6
Total	14.6	45.8	55.3

Oil	98%	6%	6%
Natural gas including LPG		5%	4%
Coal, including coke oven gas, b-f gas		5%	6%
Bio-fuels, waste, peat etc	2%	52%	65%
Electric boilers		5%	1%
Heat pumps		16%	10%
Waste heat		10%	8%
Total	100%	100%	100%

[30] Statens energimyndighet 2007a: 24-25

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Fridtjof Nansens vei 17, P.O. Box 326, NO-1326 Lysaker, Norway
Phone: (47) 67 11 19 00 – Fax: (47) 67 11 19 10 – E-mail: post@fni.no
Website: www.fni.no