Government regulation as an impetus for innovation: Evidence from energy performance regulation in the Dutch residential building sector

Milou Beerepoot\textsuperscript{a,}\textsuperscript{*,} Niels Beerepoot\textsuperscript{b}

\textsuperscript{a}OTB Research Institute for Housing, Urban and Mobility Studies, Delft University of Technology, P.O. Box 5030, 2600 GA Delft, Netherlands
\textsuperscript{b}Amsterdam Institute for Metropolitan and International Development Studies (AMIDSt), University of Amsterdam, Nieuwe Prinsengracht 130, 1018 VZ Amsterdam, Netherlands

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Abstract

The recent implementation of energy performance policy as a way to tackle energy consumption in the building sector in Europe draws attention to the effect it has on the development and diffusion of energy-saving innovations. According to innovation system literature, government regulation through norms and standards is one of the factors stimulating innovation. This paper concentrates on the role of stricter government regulation as an incentive to innovation in the Dutch residential building sector. Innovation in this sector is predominantly a process of applying incremental modifications to comply with new and stricter government regulations and standards. Energy performance policy in its current shape will therefore not contribute to the diffusion of really new innovation in energy techniques for residential buildings in the Netherlands. If diffusion of really new innovation is an explicit aim of energy performance policy then the European wide introduction of this scheme needs reconsideration.

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1. Introduction

The passing by the European Parliament of the Energy Performance of Buildings Directive in 2003 obliged all the European member states to implement energy regulations based on the concept of energy performance (European Commission, 2003). The aim of energy performance regulations in the building sector is to reduce energy consumption in buildings caused by heating, hot water production, lighting, cooling and ventilation. The energy performance standard limits the energy consumption of a building to a certain maximum level. The energy performance calculation allows the user to choose a set of energy features and to trade off between these features (e.g. higher insulation level for poorer heating system efficiency, or vice versa), as long as the energy performance standard is still met. Energy performance regulations have already proven successful in achieving energy conservation in the Netherlands (Joosen et al., 2004). The energy performance-based approach is also expected to encourage innovation. At times that standards of the Dutch energy performance policy were either introduced or tightened, an explicit expectation of the take-off of innovative energy techniques such as solar boilers was proclaimed (Ministerie van VROM, 1995; Tweede Kamer, 2004). This study aims to scrutinize the effect of energy performance policy on innovation in energy conservation technology by using data from a database of 350 energy performance calculations submitted to several Dutch municipalities from 1996 to 2003 in connection with applications for building permits. The extent to which energy performance regulations contribute to innovation has been discussed up to now on a small scale (Gann et al., 1998; Vermeulen and Hoven, 2006), but these papers do not use empirical data on the energy appliances actually used in residential buildings, or do they position the issue in the larger context of the debate on the influence of government regulations on the development and diffusion of innovations. Knowledge about the effect of energy performance...
policy can help to shape energy policy, both to improve its effectiveness and get realistic expectations of its innovative power.

The question this paper addresses is what innovation effect can be expected from introducing and regularly resetting energy performance standards for the residential building sector in the Netherlands. We use the innovation systems approach to explain our findings from empirical research on the effects of Dutch energy performance policy in the development and diffusion of energy conservation technologies in the project-based sector of the Dutch residential building industry. Energy performance regulations are based on setting a standard for the energy performance of a building. Some authors argue that regular resetting of the standard will encourage innovation in order to comply with the stricter requirements (see Weber and Dicke, 2001). Various scholars have looked at the contribution environmental policy instruments can make to the diffusion of innovation from an innovation systems perspective (see Hemmelskamp et al., 2000; Vollebergh et al., 2004; Kemp, 1995, 2000). The innovation systems literature emphasizes that in most cases innovations are not developed by individual companies but through interaction and exchange with various stakeholders operating in the same field. The characteristics of the sector then decide to a large extent what scope there is for innovation and how effective policy interventions (e.g. setting norms and standards) will be there. The literature emphasizes that norms and standards can create a platform upon which new products and technologies can be developed (see Edquist et al., 2004). Various authors, however, conclude that merely setting a standard will not lead to innovation, since it does not encourage performance any better than the standard (see Schot, 1989; Vermeulen, 1992; Driessen and Glasbergen, 2000). Others draw attention to a combination of factors such as stringency, flexibility, cost sensitivity and time allowed to achieve mandated emission reductions being highly influential to environmental technology innovation (Porter, 1991; Taylor et al., 2003).

In terms of innovation in energy techniques, a recent worldwide notion has arisen that we will need a drastic reduction of carbon-dioxide emissions in order to restrict climate change (IPCC, 2007). According to Shackley and Green (2007), a transition to a low-carbon set of interrelated technologies is needed in order to reach a large-scale reduction in carbon dioxide emissions. A “laissez-faire” approach will result in incremental technical improvements in the context of existing technologies. However, incremental innovation does not reduce overall energy use due to an increase in affluence and will therefore be unlikely to achieve large-scale decarbonization (Shackley and Green, 2007).

The Netherlands provides a good case for studying the innovation effects of energy performance policy. The Energy Performance approach was introduced there in 1996, thus enabling us to assess innovation effects in the residential building sector over a fairly long period. We start in Section 2 with a brief clarification of the innovation systems concept and explain the concept of sectoral innovation systems, then going on to discuss the various types of innovation and the innovation effect attributed to government regulation. Section 3 uses these theoretical notions to analyse innovation in the construction sector and its systematic features in the Dutch residential building sector. This provides us the platform and the constraints under which the policy intervention is operating as the residential building sector is the level targeted for the introduction of energy-saving techniques. Section 4 presents the results of an empirical study, for which about 350 Dutch energy performance permits for new residential buildings, dating from 1996 to 2003, were collected. These provide us with data on the energy conservation technologies used, since the introduction of energy performance policy in 1996 and after the standard was tightened up in 1998 and 2000. Section 5 sets out the conclusions.

2. Innovation systems

Terms such as ‘innovation’ and ‘national’, ‘regional’ or ‘sectoral’ ‘innovation systems’ are used in multiple ways in the literature, and the difference between them is often left vague (for an overview, see e.g. Cooke, 2004; Malerba, 2004; Lundvall, 2005; Sharif, 2006). Since the original interest in innovation and its systematic features, various strands of literature have evolved around this concept. In academic and policy spheres, the innovation systems concept can take on several forms based on distinct classification criteria, spatial, technological, and industrial or sectoral (Sharif, 2006). This paper starts with a brief clarification. The concept of innovation refers to the transformation of an idea into a marketable product or service, a new or improved manufacturing or distribution process, or a new method or social service (Heidenreich, 2004). Moving away from the original Schumpeterian equation of innovation with invention, the concept is now extended to cover continuous improvement in product design and quality, changes in organization and management routines, creativity in marketing, and modifications to production processes that bring cost down, increase efficiency and ensure environmental sustainability (see Mytelka, 2000).

The process of innovation is incremental, cumulative, and assimilative. In other words, new ideas that actually get to market are usually incremental improvements on existing technology. The increment can be large, but it builds upon what has gone before, hence the process is cumulative (Fri, 2003). Innovation is also an interactive process in which enterprises, in interaction with one another and supported by institutions and organizations—e.g. industry associations, R&D, innovation and productivity centres, standard-setting bodies, universities and vocational training centres, information-gathering and analysis services, and banking and other funding mechan-
isms—play a key role in bringing new products, new processes and new forms of organization into economic use (Mytelka, 2000). The emphasis on embedding innovation in networks of actors has led to the conceptualization of innovation systems in order to capture the systematic characteristics of the innovation process. An innovation system can be seen as a network of organizations, people and institutions within which the creation, diffusion and commercial exploitation of new technologies and other types of knowledge takes place (Malmberg and Power, 2005). The national systems of innovation (NSI) literature made enormous strides in defining innovation and correcting perceived wisdom about innovation processes by showing them to be not linear but interactive and introducing the important concept of ‘institutional learning’ into this more systematic analysis of innovation (Cooke, 2004). The concept was intended to help develop an alternative analytical framework to standard economics and to criticize the way it neglects dynamic processes related to innovation and learning when analysing economic growth and economic development (Lundvall, 2005). Over the last decade, various authors have focused on other levels of innovation (e.g. sectoral, regional), thereby extending the original NSI concept. A sectoral system of innovation is a collection of economic activities organized around a common technological or knowledge base in which individual enterprises are likely to be either actual or potential competitors with one another (Edquist et al., 2004). For this study (i.e. a focus on one particular sector), the sectoral system is the most convenient framework. A sectoral system of innovation (and production) is composed of a set of agents carrying out market and non-market interactions for the creation, production and sale of sectoral products (Malerba, 2004). Sectoral systems have a knowledge base, technologies, inputs and—potential or existing—demands (Malerba, 2004). They each have a particular type of innovation process, depending on the characteristics of the sector. Boundaries within a sectoral system are not static; they must be expected to evolve as the underlying problems of innovation evolve (Edquist et al., 2004). The sectoral system provides a good starting point for understanding what stakeholders are involved and how effective public policies are, as innovation policy should be sensitive to sectoral distinctions. Sectoral systems can be classified in terms of sectors predominantly organized around (a) functionally organized firms and (b) project-based firms. The innovation systems literature still focuses mainly on functionally organized firms, which are presented as bounded entities of consistent divisions and units. Project-based firms consist of project teams that work off-site in teams with many other firms, having limited contact with senior management (Gann and Salter, 2000). Project-based sectors (such as the construction sector in our case) are characterized by design and production processes that are organized around projects, the production of one-off—or at least highly customized—products and services, and the fact that they operate in diffuse coalitions of companies along the supplier–customer chain. Innovation activities in project-based firms are performed within, or closely related to, business projects, instead of in separate R&D departments (Blindenbach-Driessen, 2006). Innovation in project-based firms will be considered when we elaborate on the sectoral system of innovation in the construction sector in Section 3.

2.1. Types of innovation

Innovation should be regarded as a container term that covers a variety of processes. Lundvall (2005) characterizes it as a continuous cumulative process involving not only radical and incremental innovation but also the diffusion, absorption and use of innovation. Although the link between innovation and technology is not a necessary one, in practice, in current conceptions of both process and product innovations, the empirical literature most often takes ‘innovation’ to mean some form of technological change, either in a product or in the production of a good or service (Blake and Hanson, 2005). The basic distinction among innovations is between product and process innovations, and incremental and radical innovations (see Feldman, 2000). Innovations vary along a continuum from incremental to radical. The term ‘radical’ has been associated with revolutionary innovations, whereas ‘incremental’ is associated with innovations within a paradigm (Johannessen et al., 2001). Dahlin and Behrens (2005) emphasize that an innovation should fulfil two characteristics to be considered radical: it should be dissimilar from prior and current innovations and it should influence future innovations. Very few innovations, however, represent substantial, and disruptive, milestones; the majority of innovations are continuous, incremental improvements to products. Incremental innovations include minimal changes in the technological basis of a product which are matched by only a minimal improvement in benefits to customers (Herrmann et al., 2006). A key difficulty in the innovation systems literature is the categorization of innovations in between this basic differentiation of incremental versus radical innovation. Various authors have looked for a more refined way of differentiating between innovation processes but provide limited harmony (see e.g. Garcia and Calantone, 2002; Dahlin and Behrens 2005; Smith, 2005). Garcia and Calantone (2002) make a distinction between radical, incremental, really new, discontinuous and imitative innovations, and between architectural, modular improving, and evolutionary innovations. Inevitably, overlap between types of innovation exists within such a refined categorization. Of importance for this study is to stress that many innovations are not radical or incremental but may be new in their application within a certain sector, and therefore can be considered as ‘really new’ (see Section 4). Compared to incremental innovations, ‘really new’ innovations not just carry with them higher social and environmental benefits but also the...
premium of becoming technological leader in a certain field.
The diffusion and adoption of innovations is complex and depends on various factors. Rogers (2003) stressed that the potential adopter’s perception of the compatibility, complexity, divisibility and communicability affect the rate of adoption of an innovation. Adopters should have an incentive to change their traditional habits and practices. The adoption of alternative technological systems is often inhibited by the dominance of the present technological growth trajectory (Hall and Kerr, 2003). There is a long history of technologically superior solutions in particular fields that were not picked up by the market (see also Shackley and Green, 2007).

2.2. Government regulation and innovation

The innovative systems approach is not entirely based on a belief in the blessings or basically advantageous functioning of the market economy. Firms are not the only important actors in the approach, and local synergy could and should in some circumstances be enhanced through the creation of a local ‘agent d’animation’ or cross-firm organizer (Maskell and Kebir, 2006). Many studies emphasize that the government (or policy-making bodies) should play this role in innovation systems and that government regulation should provide an incentive for innovation. The most common reason for government intervention is market failure in achieving socially desirable objectives, which can range from international competitiveness to environmental transformation. Innovation policy has a role in bringing about industrial dialogue, particularly between producers and users aimed at mitigating the cost of coordination (Edquist et al., 2004).

The options for policy makers to fundamentally change the course of industrial development are rather limited, however, given the many regions that want to become new Silicon Valleys but have failed to do so. Because of the complexity, divisibility and communicability affect the rate of adoption of an innovation. Adopters should have an incentive to change their traditional habits and practices. The adoption of alternative technological systems is often inhibited by the dominance of the present technological growth trajectory (Hall and Kerr, 2003). There is a long history of technologically superior solutions in particular fields that were not picked up by the market (see also Shackley and Green, 2007).

The role of the government in an innovation system is to facilitate innovation through either support measures (e.g. funding public research institutes, R&D subsidies) or government regulation (i.e. norms and standards). The first role is directly interventionist or facilitating, whereas the second is to stimulate innovation indirectly, as it should encourage or force companies (e.g. by means of product bans) to make transformations. Traditional innovation policies have been designed to provide public resources for R&D and increase the incentives for firms to innovate, typical examples being tax breaks for R&D, innovation subsidies and patents (Edquist et al., 2004). These policies were basically legitimized by the concept of market failure, whereas modern innovation policies also have to deal with system imperfections (Smits and Kuhlmann, 2004). Normative R&D policy rationales (market failure, public goods) do not generally rule the de facto behaviour of decision-making actors in innovation policy arenas (Smits and Kuhlmann, 2004). Policy-making means compromising or reframing stakeholder perspectives and achieving a consensus. Public policy is very much a matter of formulating ‘rules of the game’ that facilitate the formation of operational innovation systems (Edquist et al., 2004).

Porter (1990) put forward the criticism that most of the policies that would make a real difference are either too slow and require too much patience for politicians or, even worse, carry with them the sting of short-term pain. His emphasis on radical innovation through the implementation of public policy was a new way of looking at providing incentives for innovation. He advocated the enforcement of strict product safety and environmental standards long before such ideas became fashionable, and even longer before social responsibility became part of managerial rhetoric and practice (Maskell and Kebir, 2006). Taxes, subsidies, standards and covenants are not concerned directly with innovation but should encourage the development of new technologies. The most common responses to regulation are incremental innovation in processes and products, and the diffusion of existing technology (Kemp, 2000). The stringency of regulation is an important determinant of the degree of innovation: stringent regulations such as product bans are necessary for radical technology responses (Kemp, 2000). Non-stringent regulations do not encourage companies to make radical changes that could provide cost or performance benefits. Companies will then just make sufficient product modifications or improvements to existing technology to comply with new regulations. Incremental innovation is the path of least resistance for industry and policy makers who are constrained by industrial dynamics and economic pressures (Hall and Kerr, 2003). Transitions cannot be steered by a central actor; to do so implies that such an actor has knowledge of specific objectives and knows, in advance, which of the new technologies will be the ‘winner’ (Shackley and Green, 2007). It is obvious that public authorities often lack expertise on the various technological opportunities in the market. Geels (2004) stressed that rules and regulations are a game that is played out by actors, firms, public authorities, users, scientists, suppliers, etc., acting and interacting in response to one another. Their resources (e.g. money, knowledge and tools) and opportunities to achieve their purposes, serve their interests and influence social rules are unequal. Public authorities need to be in constant negotiation with the other main stakeholders in the sectoral system to accomplish their goals.

3. The innovation system in the Dutch residential building sector

The construction industry is notorious for its complex context, caused by characteristics inherent to construction
work such as inter-organizational collaboration, an approach based on constructing unique projects every time, and power that is distributed amongst collaborating organizations (Harty, 2005). Dubois and Gadde (2002) refer to the project-based nature of the construction process as a system of ‘tight and loose couplings’. In individual projects the couplings are tight, whereas those in the permanent network are loose. Inter-firm adaptation beyond the scope of individual projects is rare, and firms tend to rely on short-term market-based exchange (Dubois and Gadde, 2002). In the complex inter-organizational collaboration involved in a particular project the contractor is a mediator and plays a key role in the construction value chain when it comes to adopting innovations. Since it is the contractor who has the contacts with both the institutions developing new products (materials and components suppliers, developers of energy appliances, specialist consultants) and the ones that need to adopt these innovations (clients, regulators and professional institutions), he has to be convinced of the benefits of innovation in order to apply them (Miozzo and Dewick, 2002). Because innovations in construction are not implemented in a firm itself but as part of the projects in which firms are engaged, most innovations also have to be negotiated with one or more parties in the project coalition (Miozzo and Dewick, 2002). Since every construction job is unique there are hardly any economies of scale, hence there is little reason for contractors to invest in innovation (Pries and Janszen, 1995). The financial organization of the construction sector also has direct influence on innovation capability. The industry is dominated by intense price competition (Pries and Janszen, 1995). The practice of awarding contracts based on the lowest cost tender is likely to act as a constraint on innovation, since it gives contractors very little scope to change design specifications and introduce innovations (Miozzo and Dewick, 2002). Also, it is quite common for contractors to have relatively little fixed capital, since they do not own any significant assets other than buildings under construction and, in some cases, land.

3.1. Characteristics of the Dutch building sector

The residential building industry is highly dependent on geographical factors such as availability of materials and building sites. Building sites are scarce in the Netherlands, as it has one of the highest population densities in the world, and land use is therefore government-regulated (Wildt et al., 2005). The Dutch building sector is also tied down by technical regulations on safety, health, functionality, sustainability and energy consumption. In many cases it is municipal authorities that commission construction work, which often means working on sizeable developments at the same time. The Dutch building sector is known for a large share of small enterprises. The portion of construction enterprises employing more than 100 man-years is only 1.6% of the total number of registered construction companies (EIB, 2002). Overhead in small companies is limited, resulting in relatively little means for R&D expenditure. The computerization level of the construction sector is—compared to other industries—still underdeveloped. Most small and medium construction enterprises operate on a local level. International activity is only found at few large companies.

Competition in the building sector is usually imperfect due to the long life span and the place-bound character of buildings (Priemus, 2004). Furthermore, private commissioning is rare in the Netherlands, with only 15% of residential buildings being commissioned directly by clients, compared to neighbouring countries such as Belgium, where 70% of new residential building is commissioned by private clients. Innovation led by client demand is therefore hard to achieve in the Dutch residential building industry. A recent study showed that the primary motive for innovation in the Dutch construction industry is to improve productivity (75%) while only 25% of innovation appeared to be in response to specific market demands (Pries and Doree, 2005). Although the market motive seems to be growing recently, the construction industry continues to be inward-looking, rarely recognizing customer needs (Pries and Doree, 2005).

Due to the characteristics of the Dutch construction industry as described above, it is being criticized since time immemorial for having a conservative nature thus causing restraints rather than encouragement for innovation (Jacobs et al., 1992). The sector is subject to a strong path-dependent development trajectory whereby old routines are too pervasive to make substantial changes in techniques applied.

3.2. Energy innovation and performance regulation

There are a number of obstacles to the introduction of innovations in the residential building sector. Investment in energy-saving technology, moreover, creates an advantage for users rather than builders. Low-energy buildings could be designed so as to create a market niche for construction firms. Since the sector competes mainly on price rather than quality, however, this argument does not create sufficient incentive to apply energy innovations. The demand side in the sector is weak, thus aggravating the situation that innovation is not used for competitive positioning. Even where clients could exert an influence, households’ relatively low expenditure on energy (4.5% of their total expenditure, only half of which goes on heating) causes a lack of user demand for more energy-efficient housing (Gann et al., 1998). As energy prices increase consumers are likely to pay more attention to the issue of energy-efficient housing, but the low price elasticity of energy will limit the response (Haas and Schipper, 1998; Jeeninga and Boots, 2001). Another barrier to consumers evaluating the life cycle costs of a building is the lack of transparency when it comes to energy efficiency, which places a damper on the demand for low-energy housing
(Sprei and Nassen, 2005). Research by Sprei and Nassen (2005) demonstrates that firms regard investing in the energy performance of buildings as an economic risk. This market failure justifies government intervention to achieve energy conservation in the building sector.

The energy consumption of new buildings in the Netherlands has been regulated since 1975 in the wake of the oil crisis in 1973–1974. The recent maturation of prescriptive standards into energy performance standards is supposed to allow firms to decide for themselves how to meet the standard. Flexible options for meeting the energy performance standard create competition between different technologies, e.g. insulation versus heating technology (Weber and Dicke, 2001). According to these authors, energy performance regulations can speed up both innovation and market penetration in the building sector if requirement levels are tightened up stepwise and specific mechanisms for dealing with innovations such as flexibility, reliability and cost-effectiveness are included. Given the complexity of the construction process, however, it is disputable whether design teams take sufficient advantage of the flexibility they have to choose energy technologies: research indicates that they will first try to meet the energy performance standard by using conventional technologies, e.g. efficient boilers and increased insulation (Essers and Mooij, 2001). Although the regulations offer flexible ways of meeting the standard, the standard itself still sets a required level; it does not provide any incentive to innovate beyond that level. Interviews in Sweden show that the energy performance standard is perceived as a guideline and it is uncommon for people even to consider the profitability of additional investments in energy efficiency (Sprei and Nassen, 2005). Gann et al. (1998) noted that when the energy regulations in Great Britain were revised, this was taken up by manufacturers of construction components as an incentive to improve their products, but problems were often experienced in achieving market entry for these products, owing to regulatory conformance mechanisms and the structure of the construction value chain (Gann et al., 1998). The same thing happened in the Netherlands with the introduction of efficient gas condensing boilers: although this technology was brought onto the market in 1981, its diffusion was very slow (Brezet, 1994). It was only when the energy performance regulations were introduced in 1996 that the efficient gas condensing boiler had become the standard for new residential building in the Netherlands.

Energy performance regulations in the building sector mainly address construction, which needs to meet certain requirements as regards, e.g. minimum insulation levels or maximum permitted energy use. It is the manufacturers of materials (insulation, etc.) and appliances that need to respond to the building regulations and produce innovative solutions to meet these requirements. The government does not impose product quality requirements directly on upstream materials and components manufacturers. The challenge for regulators is to encourage upstream innova-

4. Empirical data on the diffusion of energy-saving innovations in the Dutch residential building sector

The analysis of the innovation system of the Dutch construction sector demonstrated that the conditions for
innovation in energy-saving techniques are not very favourable. A strong path dependency is indicated, implying an important constraint in discussing innovation in the building sector.

We constructed an explanatory model in order to ascertain the relative influence of the EPC regime in relation to other factors that influence technological development in the residential building sector, using which—after adding variables to the database—we were able to perform regression analyses. We combined a general model for evaluation research introduced by Mayer & Greenwood (Vall and Leeuw, 1987) with the framework for explaining the diffusion of innovations in new office buildings as developed by Vermeulen and Hoven (2006). Vermeulen & Hovens’ framework focuses on decision-making but also puts forward explanatory variables for the macro-context, consisting of the ‘macro-economic situation’, ‘market demand in terms of environmental awareness in society’ and ‘energy price developments’. They did not take the ‘macro-context’ factor into account, however, since their research focuses on one moment in time. Our research covers a period of 8 years (1996–2003) and therefore specifically analyses the ‘macro-context’. The combination of these two approaches is shown in the explanatory model in Fig. 1.

Mayer & Greenwood’s general conceptual model for policy evaluation describes the policy process from start to finish, based on a series of causal relations. In this case, the independent variable is the actual practical intervention designed to result in the policy goals (the dependent variable) being achieved. Fig. 1 shows how the innovation effects of introducing energy performance policy are primarily a side effect of the actual policy goal of reducing CO₂ in the building sector. Our research focuses on the grey-shaded area of the policy process, which shows the correlation between introducing and tightening up the Energy Performance Standard (in 1996, 1998 and 2000) and the use of improved and new technologies in energy concepts for residential buildings. Factors outside the system can also encourage or prevent the development and diffusion of new energy technologies: these are referred to as advancing factors (adjuncts) and restricting factors (constraints). We used the adjuncts and constraints as described by Vermeulen and Hoven (2006) for the macro-context, adding the factors ‘subsidies’, ‘promotional campaigns’ and ‘autonomous technological development’ to their variables ‘macro-economic situation’, ‘market demand’ and ‘energy prices’. The innovation system of

<table>
<thead>
<tr>
<th>Dwelling type</th>
<th>Floor surface (m²)</th>
<th>Expected energy consumption for EPC 1.0 (GJ)</th>
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<tbody>
<tr>
<td>Terraced dwelling</td>
<td>123</td>
<td>43</td>
</tr>
<tr>
<td>Detached dwelling</td>
<td>220</td>
<td>89</td>
</tr>
<tr>
<td>Apartment</td>
<td>75</td>
<td>26</td>
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Fig. 1. ‘Influence of energy performance policy on energy innovation’ research model.
the construction sector, shapes the environment for policy intervention.

To analyse the innovation effects of energy performance policy on residential building in the Netherlands, we collected energy performance calculations, used when applying for building permits, in the files of one municipality and two consultancy companies. The collection of 352 calculations is equally distributed over the years 1996–2003 and represents all the possible types of residential building. A single energy performance calculation can cover an apartment building or a block of similar linked housing. It was not possible to find the number of dwellings the calculations represented; we estimate that the 352 calculations represent about 2000 housing units. It is not possible to provide details of the precise percentages of technologies used in the Netherlands, but the database is thought to reflect the general trend. The data in the energy performance calculations enable us to extract the technologies used for insulation, space heating, hot water production and ventilation in the buildings.

The next step was to include the advancing and restricting variables for the macro-context in our database. We included Dutch national gas prices per year for domestic use derived from Statistics Netherlands (CBS, 2006). Dutch national gas prices showed a steady rise during the years 1996–2003. The rise of yearly gas prices reflects the basis on which decision making for energy techniques has taken place. National yearly gas prices are preferred to future energy prices since the latter are highly speculative and imply the use of scenario studies. Economic growth was included in the database in the form of investment in residential building during the 1996–2003 period. Our analysis of the innovation system in the Dutch residential building sector leads to the conclusion that market demand is a negligible factor in the Netherlands. Subsidies have been provided for solar thermal boilers and heat pumps. Research into the influence of energy performance policy on the use of solar thermal boilers indicates that subsidies can until 2003 be regarded as a stable factor over the years (Beerepoot, 2007). Financial incentives for heat pumps, which consisted of fiscal incentives until 2000 and a subsidy scheme from 2000 until 2003, can be considered stable during the period of our analysis. Promotional campaigns for both solar boilers and heat pumps have been going on for a long time and remained constant during the 1996–2003 period. Autonomous technological development is not included in the database as there are no data available on the subject. Section 2 showed that innovation varies along a continuum from incremental to radical, and many innovations are not radical or incremental but may be new in their application within a certain sector. The last category is what Garcia and Calantone (2002) call ‘really new’ innovation. In our database we categorized all the technologies used in three categories:

(1) Technologies that represent the ‘state of the art’ in 1996, when energy performance regulations were introduced in the Netherlands.
(2) Technologies that show an improvement on the 1996 ‘state of the art’: incremental innovations.
(3) Technologies that are new to the Dutch residential construction sector compared to the 1996 ‘state of the art’: really new innovations.

As we explained in Section 2, radical innovations are rare, since only very few innovations represent substantial milestones. It was not possible to identify any radical innovations in the construction sector so we left this category out of our analysis. In an earlier study we described the development of techniques for hot water production, heating, insulation and ventilation (see Beerepoot, 2007). Techniques for space heating appeared to be rather similar to techniques used for hot water production, though less diversified since solar boilers and heat pumps are less commonly used for space heating. Development in insulation could be demonstrated in terms of increasing insulation levels but cannot be categorized in terms of “innovativeness”. Our database of ventilation techniques (covering the period 1996–2001) only showed incremental innovations. We therefore focused on the technologies used for hot water production, since this is where there is the greatest variation in available technologies. Fig. 2 shows the water heating systems used from 1996 to 2003 in the Netherlands in the new residential buildings in our database.

As Fig. 2 shows, in the 1996–2003 period we found seven technologies used, ranging from regular gas condensing boilers, efficient gas condensing boilers and high-efficiency gas condensing boilers (two versions) to solar boilers, heat delivery systems (mostly district heating) and heat pumps. We categorized each of the seven technologies in one of the three innovation categories according to their rate of adoption in 1996, at the time of introduction of the energy performance policy in the Netherlands. In the Netherlands energy supply is being dominated by natural gas since the discovery of huge natural gas fields in the northern part of the country. In 1988, 96% of Dutch households were connected to natural gas distribution (Brezet, 1994). In 1992, 73% of the Dutch households used gas condensing boilers, while at the same time 11% of households were being connected to district heating and 16% of households made use of local heating (Brezet, 1994). Efficiencies of gas condensing boilers have been improved continuously, mainly driven by rising energy prices such as caused by the energy crisis in the 1970s. The first efficient gas condensing boilers with an efficiency of 90% on HHV and 100% on LHV\(^1\) was already introduced in 1981 (Brezet, 1994). A long and slow diffusion path has made the efficient gas condensing boiler the most common

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\(^{1}\)Higher heating value (HHV)—or gross calorific value—represents the efficiency of combustion, including the condensation energy of water vapour. European standards for gas condensing boilers are often based on lower heating value (LHV), which excludes the condensation energy of the water, resulting in efficiencies of over 100% for condensing boilers.
A technique for domestic hot water for new residential building in the second half of the 1990s. Following the energy crisis of the 1970s, one of the options for energy savings was expected to be district heating, which resulted in a systematic governmental support for district heating from 1977 to 1984 (Vermeer, 2002). Regular gas condensing boilers, efficient gas condensing boilers and heat delivery by means of district heating are taken as the state of the art techniques in 1996 and categorized as such in our analysis. High-efficiency gas condensing boilers (with efficiencies of 95% on HHV, 104% and 107% on LHV) are considered to be incremental innovations, since they show improvements on the 1996 state-of-the-art efficient gas condensing boiler. Although the first heat pumps were introduced in the Dutch market by the 1980s, a combination of factors caused that this technique was still considered to be experimental by the year 1996 (Vermeer, 2002). At the time the energy performance regulations were introduced about 2500 heat pumps had been installed in dwellings (existing and new) in all the Netherlands (Vermeer, 2002). Solar boilers were developed and introduced in the 1970s as a consequence of the energy crises. Decreasing energy prices in the 1980s diminished interest in solar boilers, but in the 1990s as a result of increased attention for the environment, numbers of applied solar boilers rose (Zegers, 2003). In the year 1996 about 3500 solar thermal systems were installed in a total of about 80,000 new residential buildings that were built that year (Holland Solar, 2007; Zegers, 2003).

Decisions on whether to apply new techniques depend on the costs related to the effect they have in reducing the energy performance coefficient and on the level of energy performance that needs to be realized. However, both costs and effect on the energy performance coefficient are very project specific. Costs depend on features such as numbers of dwellings to be built while energy performance effect can vary considerably, depending on shape and size of the dwellings influencing the calculation. Really new techniques such as heat pump boiler or solar system naturally have higher costs but also result in a considerable improvement of the energy performance coefficient. Table 2 gives an indication of costs of most relevant energy techniques for hot water production in the year 2000 and the effect in reducing the energy performance standard (Scheepers and de Raad, 2000).

Solar boilers and heat pumps are categorized as ‘really new’ to the construction industry compared to the state of the art in 1996. By attaching these labels to the variables for ‘hot water production technologies used’ we developed a new variable expressing the innovativeness of the technologies used, based on the three categories mentioned above. This variable was used to create two dichotomous variables, one indicating whether or not a technology represents an incremental innovation and one expressing whether it represents a really new innovation. These variables enable us to analyse the correlation between the introduction and tightening-up of energy performance regulations in the Netherlands and incremental or really new innovation in hot water production technologies. We also had a variable ‘EPC regime’ representing the three periods during which the Energy Performance Standard limits remained constant. Table 3 shows the exact levels of the Energy Performance Standard during the years 1996–2003.
The introduction of a new and tighter standard has each time well in advance been prepared in consultation with the building industry. The adjustment of standards has each time been announced between 6 and 12 months before introduction. Adjustments have always taken place the 1st of January meaning that documents for building permits handed in the 1st of January had to meet the new requirements. We therefore do not expect lags between new standards and applied energy techniques to be an issue affecting the analysis. We first performed a \( \chi^2 \) analysis between (a) the variable ‘EPC regime’ and (b) the dichotomous variables ‘incremental innovation’ and ‘really new innovation’. Both tests produced significant results, i.e. there is a statistical association between the EPC regime and both incremental innovation and really new innovation. The strength of the correlation can be determined by means of a correlation analysis. A perfect correlation between two variables is represented by a correlation coefficient of 1; a coefficient of 0 means that there is no correlation. Kendall’s τ correlation coefficient was chosen, since the data are non-parametric and there are a large number of tied ranks. The correlation coefficient squared \( R^2 \) is a measure of the amount of variability in one variable that is explained by the other. Table 4 shows the results of the correlation analysis.

Table 4 shows a correlation of 0.443 between the EPC regime and the application of incremental innovation, indicating that the EPC regime accounts for 19.6% of the variability in applying incremental innovations. This leaves about 80% of the variability still to be accounted for by other variables. The EPC regime shows a correlation of 0.2 with the application of really new innovation, which means that it accounts for a negligible share (not more than 4%) of the variability in applying really new innovation. In order to ascertain the relative effect of the EPC regime on the diffusion of either incremental or really new innovation, we used the independent variables ‘EPC regime’, ‘InvestmentResidentialBuilding’ and ‘GasPriceDevelopment’ in a regression analysis. We used the two dichotomous variables representing whether an ‘IncrementalInnovation’ or ‘ReallyNewInnovation’ had been applied. Using the dichotomous dependent variable we can employ logistic regression analysis to investigate the relative influence of the independent variables. We first tested for multicollinearity (the strength of the correlation between two or more predictors) by means of the collinearity diagnostics of the linear regression analysis. In both the multicollinearity tests for (a) incremental innovations and (b) really new innovations, VIF factors vary between 2 and 3. Though there is some multicollinearity they do not exceed 10, so we accepted this for our further analysis.

Table 5 shows the results of the logistic regression analysis. Logistic regression does not have an equivalent to the \( R^2 \) found in linear regression, but the Cox & Snell \( R^2 \) is

\[ \text{Table 2:} \text{Indication of costs of most relevant energy technologies for hot water production (2000) and effect in Energy Performance Coefficient (EPC) related to reference: E-boiler 107%} \]

<table>
<thead>
<tr>
<th>Indication of costs (2000)</th>
<th>Effect in ΔEPC</th>
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</thead>
<tbody>
<tr>
<td>E-boiler 107% (combi-boiler, producing for hot water and space heating)</td>
<td>€1,500</td>
</tr>
<tr>
<td>Heat pump boiler (extracting heat from ventilation air, additional boiler for space heating is required)</td>
<td>€1,800 (€1,300)</td>
</tr>
<tr>
<td>Solar thermal system (2.8 m², producing for hot water only, additional boiler is required)</td>
<td>€2,000 (€1,500)</td>
</tr>
<tr>
<td>Solar thermal system (5.6 m², including boiler, also producing for space heating, combined with Low Temp Heating)</td>
<td>€3,900</td>
</tr>
</tbody>
</table>

\[ \text{Table 3:} \text{Levels of the Dutch energy performance standard during the years 1996–2003} \]

<table>
<thead>
<tr>
<th></th>
<th>EPC 1.0</th>
<th>EPC 1.2</th>
<th>EPC 1.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td></td>
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<td>1997</td>
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<td>2002</td>
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<tr>
<td>2003</td>
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</tbody>
</table>

\[ \text{Table 4:} \text{Association (Kendall’s τ) between EPC regime and selected parameters} \]

<table>
<thead>
<tr>
<th></th>
<th>Kendall’s τ correlation coefficient</th>
<th>Correl. coeff. squared ( R^2 )</th>
<th>Sig. (two tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incremental innovation</td>
<td>0.443*</td>
<td>0.196</td>
<td>0.000</td>
</tr>
<tr>
<td>Really new innovation</td>
<td>0.200*</td>
<td>0.04</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (two tailed).

The interpretation of whether the value of \( R^2 \) is acceptable is difficult to answer because it depends on the scientific field from which the data are taken. Whereas in physical sciences quite accurate predictions are possible in social sciences, of which our research is an example, prediction is much more difficult (Stevens, 1996). Our opinion is that in this research an \( R^2 \) of below 10% is not acceptable. We also think that an \( R^2 \) of 20% is a rather low level, but that it can be used to make statements about the relation between innovation and energy performance policy.

Since multicollinearity cannot be tested by means of logistic regression analysis, we used the collinearity diagnostics of the linear regression analysis to produce the VIF. VIF factors higher than 10 are considered to be a concern, although some say that if the average VIF is greater than 1, multicollinearity may already be biasing the regression model (Field, 2000).
a pseudo-$R^2$ statistic.\(^4\) The Cox & Snell pseudo-$R^2$ statistics from our logistic regression analyses are very similar to the adjusted $R^2$ from the linear regression analyses. The logistic regression analysis, similarly to the linear regression analysis, suggests that the model explains a considerable amount of the variance in incremental innovation applied, but it only explains a negligible share of the variance in really new innovation applied. In both cases it is mainly the EPC regime that influences the variance in either incremental or really new innovation (expressed as Exp (B)).

The significance levels of the variables ‘InvestmentResidentialBuilding’ and ‘GasPriceDevelopment’ are sometimes fairly high, indicating that they have low impact on the dependent variables ‘Incremental innovation’ and ‘Really new innovation’. The finding that mainly energy performance regulations have influenced the developments in energy techniques while developments in gas prices and investment in residential building had a negligible effect, confirms some general notions in earlier studies. Increase of gas prices is having a very low price elasticity and the effects of increased energy prices are therefore considered to be relatively small (Joosen et al., 2004). The investment in residential building did not influence innovation in energy techniques, which coincides with the general market imperfections of the Dutch housing market.

### 5. Discussion and conclusions

The objective of this paper was to identify whether energy performance regulations encourage innovation in energy-saving technologies in the Dutch residential building sector. The conclusions of the literature on innovation systems as to whether resetting environmental standards encourages innovation are mixed. Critics say this mainly encourages firms to make incremental modifications to existing products in order to comply with stricter norms and standards. The sectoral innovation systems literature emphasizes how the characteristics of a sector determine the scope for innovation within that sector. This study used data from energy performance permits for residential buildings dating from 1996 to 2003 in order to assess the innovation effect of resetting energy performance standards during this period.

The empirical analysis in this paper shows a significant correlation between the EPC regime and both ‘incremental’ and ‘really new’ energy-saving innovations in hot water technologies in the Dutch residential building sector during the 1996–2003 period. Whereas the correlation between the EPC regime and incremental innovation is relatively strong ($R^2 = 19.6\%$), that between the EPC regime and really new innovation ($R^2 = 4\%$) is negligible, however. The logistic regression analyses confirm these findings, showing at the same time that related factors, such as changes in the gas price or in the amount of housing investment, had hardly any influence on incremental or really new energy-saving innovation in the Dutch residential building sector. This study demonstrates that energy performance policy in the Netherlands did not contribute to the diffusion or development of really new innovation in hot water production technologies during the 1996–2003 period. It partly contributed to the improved efficiency of conventional hot water production technologies, but it did not result in solar hot water boilers or heat pumps taking off to any significant extent. The improvements in the efficiency of conventional technologies were sufficient to meet the tighter Energy Performance Standard. Further tightening of the Energy Performance Standard in 2006 is expected to sustain this situation. New standards will continue to be achieved using conventional technologies such as gas condensing boilers, whereas new technologies such as heat pumps will only be used if they enjoy additional government support in the form of grants.

The paper has identified how the project-based nature of the construction industry is the main obstacle to ‘learning-rich’ collaboration between the various stakeholders, preventing tight couplings from existing in the permanent network, since tight couplings with many other firms exist only for the duration of the project. The project phase is dominated by negotiation and heavy interdependence between the partners involved in the chain, from designer or developer to supplier and constructor. At the same time, the sector is dominated by price competition and the risk of market failure owing to the long lifespan and the location-bound nature of buildings. Every construction job is unique, hence there are hardly any economies of scale. As a result of the complex nature and defensive character of the building process, builders are generally unable to be flexible in using different technologies so as to comply with the energy performance standard.

Our case study provides an example of a situation where innovation is supposed to take place in a project-based environment, which has loose couplings in the permanent network, undifferentiated user demand and limited willingness on the part of those who are expected to introduce the scheme. Such market failures and sectoral weaknesses do not favour innovation in energy-saving technologies. Government regulation through norms and standards is supposed to take the place of absent user demand. In our

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\(^4\)As the Cox & Snell statistic does not indicate what $R^2$ means in linear regression (the proportion of variance explained by the predictors), this statistic has to be interpreted with great caution.

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**Table 5**

Innovation explained by policy, gas prices and investment in residential buildings

<table>
<thead>
<tr>
<th>Model: Cox &amp; snell $R^2$</th>
<th>Incremental innovation 0.238</th>
<th>Really new innovation 0.059</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sig. Exp ($\beta$)</td>
<td>Sig. Exp ($\beta$)</td>
</tr>
<tr>
<td>Investment residential building</td>
<td>0.019 1.137</td>
<td>0.045 0.867</td>
</tr>
<tr>
<td>Gas price development</td>
<td>0.155 1.044</td>
<td>0.077 0.929</td>
</tr>
<tr>
<td>Energy performance policy</td>
<td>0.000 4.485</td>
<td>0.002 3.070</td>
</tr>
</tbody>
</table>
case study, however, such regulations have not been forceful in initiating ‘radical’ or even just ‘really new’ innovations. It confirms research indicating that non-stringent government regulation primarily results in the diffusion of incremental innovations.

The study of the innovation system of the construction sector and the empirical study on innovativeness of energy performance policy in this sector provide us with two issues that need further research. First, it appears that energy performance standards have not been stringent enough during the period 1996–2003. Dutch energy performance policy started out with a standard representing normal building practice and was tightened up in such a way that it was always possible to comply with the new standard by improving conventional technologies. Hence, the only technology development that has taken place is improvements in the efficiency of conventional technologies; no really new innovation has taken off.

Second, it is questionable whether energy regulations target the right level of the value chain in the construction sector. The project-based nature of this sector does not provide a favourable environment for the effectiveness of energy performance policy, based on trading off technologies resulting in most economic-efficient solutions. Since our empirical data indicate that incremental innovation is only to some extent related to energy performance policy, it still leaves us with 80% of variability to be accounted for by other factors. Contractors are supposed to introduce energy-saving innovations which do not generate direct returns to them or strengthen their competitive advantage. It would be more effective to target manufacturers of energy technologies directly and encourage them to innovate.

The need for a drastic reduction in CO2 reduction—being a socially desirable objective that is difficult to realize on a market basis—justifies the use of energy policies. In order to reach a new set of low-carbon technologies, incremental innovation alone will not suffice. Energy performance policy in its current shape will result in incremental innovation and relatively reduced energy consumption by paying attention to the energy consumption in buildings caused by heating, hot water production, lighting, cooling and ventilation. It can be questioned however, whether this will result in an overall CO2 reduction since affluence, e.g. by using more appliances or lower occupancy rates per dwelling, can nullify the effect. Policy makers have to be aware that the effect of energy performance policy is limited and will not result in the take-off of really new innovation if the standards are not really stringent.

This study illustrates that more research is needed into the level of sectoral systems that should be targeted for policy measures to be effective. It is also questionable whether government regulation in a sector that suffers from both market failures and innovation system failures can be used to produce innovation. Government policies could just aim at influencing the ‘rules of the game’, bringing together different interests and tackling the obstacles in sectoral innovation systems in a project-based environment. More research is needed into innovation systems in project-based sectors and how the networks in these sectors can be strengthened. Most countries, for example, have a huge project-based residential building sector, but it has seldom been the subject of research into innovation systems.

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