THE IMPORTANCE OF LEARNING IN SUPPORTING ENERGY EFFICIENCY TECHNOLOGIES

A Case Study on Policy Intervention for Improved Insulation in Germany, the UK and Sweden

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Abstract

To combat climate change, different types of initiatives and policy instruments are required to support the development and dissemination of new energy efficient technologies. What type of policy instruments shall be used is, however, not pre-determined. To advance knowledge in how to design successful policy instruments, evaluations and deep-analyses are needed; this to better understand the role policy instruments have on technical change, changes in the innovation system and essential learning processes. The objective of this study is to analyze the introduction of emergent energy efficiency technologies, focusing on improved insulation in Germany, in the UK and in Sweden. The study has assessed the effect policy instruments have had on different learning processes, such as learning-by-searching, learning-by-doing, learning-by-using and learning-by-interacting. The assessment shows that learning-by-searching has been supported through private funded initiatives and thus being an essential driver for improved technologies. Learning-by-doing has been intense due to the highly concentrated market and resulted in significant production cost reductions. Processes of learning-by-using have mainly got private support, often in a very fragmented way, through intermediaries and thus with a lack of involvement of end-users, which led to limited learning. Today, European initiatives and voluntary schemes are the main facilitators of learning-by-interaction and further technology change.

Keywords
Learning, building, insulation, policy instrument, technology change.

1. Introduction

The need for technological change, to meet the challenge of climate change and march the path of sustainable development, has been acknowledged and reviewed in details previously (see e.g. IEA, 2008 and 2010). Innovative energy technologies are required to make this change happen, both in the energy supply and end-use side. Energy efficient end-use technologies have been neglected so far; although scenarios show that a significant part of future greenhouse gas reductions is expected to be due to more efficient energy end-use (IEA, 2008 and 2010, McKinsey, 2009). To make technology change, governmental policy interventions are required.

To make it influential, the design and impact of these interventions shall be assessed so that we can provide insights into how various policy strategies have, or have not, supported successful trajectories of innovative energy efficient technologies. These insights are essential tools to identify crucial elements of policy programmes and thereby improve policy interventions.

Recently, a range of studies have provided central knowledge and insights in policy interventions for energy supply technologies. Some of these have had a system-oriented innovation approach (see e.g. Neij & Åstrand 2006, Hekkert et al., 2007; Bergek et al., 2008); and some have assessed the effect of different policy instruments on learning processes in the innovation system (see e.g. Kamp et al. 2004). To further advance this knowledge, assessments and insights on energy efficient end-use technologies are essential.

The objective of this study is to analyze the introduction of emergent energy efficient technologies, focusing on improved mineral wool insulation and policy instruments applied in Germany, in the UK and in Sweden to support the development and diffusion of such technologies. Insulation is one of the most important elements to achieve energy efficiency in the building sector. Whereas the building sector stands for close to 40% of the total energy use worldwide (Laustsen 2008), inefficient insulation alone represents a large part of heat leakage of the building envelope. Improved insulation levels are essential for meeting future challenges.

1.1 Methodological and Conceptual Framework

To advance knowledge in policy intervention for technology change, the study assesses the effects that policy instruments have had on various learning processes, focusing on the processes of learning-by-searching, learning-by-doing, learning-by-using and learning-by-interacting. The study analyzes as well how these learning processes contributed to crucial innovation activities, such as the development of knowledge, access to resources, the development of markets and the development of actors and networks. The processes of learning are acknowledged by several authors to be the most significant processes for innovation and technological change (see e.g. Kamp, 2004; Lundvall, 2007, Jensen, 2007). As learning per se is difficult to measure, based on literature review on learning, a theoretical framework on conditions for learning was applied. Using this framework the presence of the underlying factors facilitating different learning processes was identified and based on these conditions we analysed the presence of different learning processes and illustrated how different learning processes have been addressed by various policy instruments over time. The learning conditions were investigated through interviews with product developers and other representatives of insulation manufacturing companies, research institutes and authorities as well as other professionals in the field. In total 15 interviews were conducted. For detailed application of learning process as a research approach, see Kiss & Neij (2010). The studied learning conditions for technology change are based on literature review (see Kiss & Neij (2010)) and then arranged and presented according to which crucial activities of innovation they are directly supporting: knowledge development, access to resource, market development and development of actors and networks.

1.2 Outline

The outline of the paper is as follows. The study starts with a short introduction to the research approach on learning and innovation *"Learning for technology, market and network development"* and how they have been applied in the analysis. It is followed by an overview to essential *policy frameworks* in the three countries. The analysis provides an insight in the *development paths* of technology, resources, markets and actors for improved insulation through the assessment of *learning* processes. The *conclusion* summarizes the role of different policy instruments in the innovation system for improved insulation levels in buildings.

2 Policy instruments for improved insulation

Policy intervention for improved insulation in Germany, the UK and Sweden has been characterized by different measures over time. Until the 1980s, building codes paved the way for better performing walls with thicker insulation, while from the 1980s the market uptake has been supported by financial incentives of various types. Since the 1990s, voluntary standards, such as passive houses gave the first signals to market actors on the need for better performing products and more collaboration for the development and installation of these products. European initiatives of the 2000s, opened a window of opportunity for market actors to officially collaborate and find system solutions for more efficient energy use in buildings. The private investments in product and technology development have always been crucial in the insulation industry.

2.1 Germany

Germany has a long history of addressing energy efficiency in buildings. Building regulations targeting increasingly lower energy consumption in buildings have been in place since the 1970s, financial incentives with the involvement of KfW Bank from the 1980s and the passive house voluntary measure from the 1990s. The first direct insulation requirements date back to 1952 ("DIN 4108"), and mostly focus on quality issues, such as avoiding structural damages and poor hygienic conditions in residential buildings (Gesamtverband Dämmstoffindustrie, 2007). First, the Energy Saving Act (EnEG) in 1976 followed by the Thermal Insulation Ordinance (WSchVO) in 1977, following the two energy crisis of the 1970s, required a maximum value for heat transmission either as average U-value of the building envelope or by means of specific U-values for each of the building components in new buildings. The importance of the proper refurbishment of existing buildings has been acknowledged early on and became part of the thermal insulation ordinance in 1984. The ordinance has been continuously upgraded between 1977 and 2009 and required approximately 30% better energy performance by each upgrade. It has reduced the average energy demand for heating in new buildings from about 170 kWh/m^2y to less than 40 kWh/m^2y in the past 30 years, see the development of the requirements of the Energy Saving Ordinance (EnEV, before WSchVO) in Figure 1.

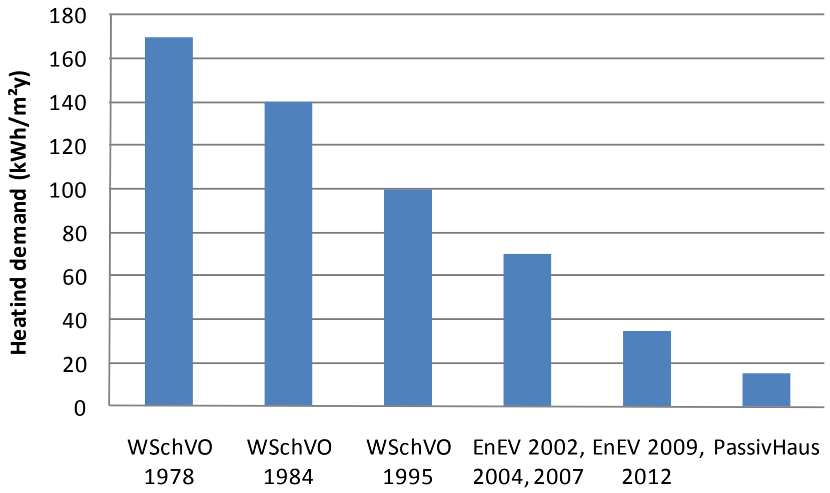

Figure 1: Impact of the strengthening of building codes in Germany (based on Witt, 2008)

Until 2002, there was no general increase in the insulation standards directly associated to these requirements, since lower performing insulation of the building could be compensated with the installation of a highly efficient heating system (BMVBS, 2007). The EnEV takes a new approach by using an energy performance indicator based on the primary energy demand to limit the energy demand for heating of buildings while keeping the previously valid heating systems regulation. Therefore it stipulates the U-values for different building components. The upgrade of EnEV in 2009, puts 15% more stringent requirements on the thermal performance of the building envelope (BMVBS, 2010). The different energy saving regulations which have been adopted and updated since 1976 have driven a clear trend towards reduced energy consumption in buildings.

Heating energy demand actually decreased by about 30% as a consequence of the implementation of thermal insulation ordinances adopted between 1978 and 1993 (Geller et. al, 2006), which was most probably rather due to improvement measures of domestic heating systems than substantial improvements in insulation. The 2002 ordinance triggered improvements in the building envelope, and thus increased insulation thickness, see Figure 2.

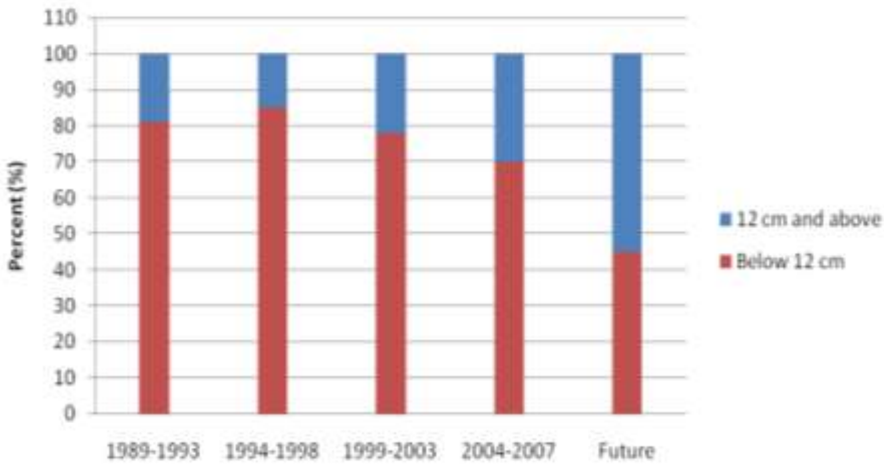

Figure 2: Evolution for insulation thickness for external wall application (BMVBS, 2007)

Germany has been recognized for many years as pioneer in terms of allocating funds for the energy efficient upgrade of buildings. Funds for energy efficient retrofitting administered by the KfW reconstruction bank have been available since the 1980s, but the uptake was fairly slow at that time. Under the CO2 Building Rehabilitation Programme, the KfW administers several funds, such as Energy Efficient Rehabilitation Programme and the Energy Efficient Construction Programme, both including thermal insulation measures. Since 2001, more than 1.7 million dwellings have been retrofitted according to energy efficient criteria. From

2009, the incentive programmes have been restructured to promote existing and new houses fulfilling more stringent standards. The KfW-Effizienzhaus 55 promotes houses using 55% of the maximum level primary energy use of the required level in EnEv 2009, while KfW-Effizienzhaus 70 promotes houses using 70% of the maximum allowed level of the required primary energy demand. Upfront costs and long payback periods have traditionally made public financial support highly important to stimulate the general interest in energy efficient improvements among homeowners. Energy efficient upgrades in buildings have increased in the last decade from a yearly rate of 1.6% between 1994-1998 to 1.8% in the period 1999-2003 and 2.2% between 2004-2006. Of all energy related upgrades in buildings, 40% were related to insulation (BMVBS, 2007). The share of funded retrofit measures that include insulation upgrades shows an overall increasing trend.

Germany's approach to promote greater energy efficiency in buildings has also been based on the promotion of much higher energy efficiency standards than the ones required by legislation. According to the German passive house standard, established by the Passive House Institute in 1997, requirement for the thermal performance of insulation is very high. U-values for building components shall be within 0.10-0.15 W/m^2K and particular attention is given to the airtightness of the building envelope and the avoidance of thermal bridges. The house cannot use more than 15 kWh/m^2 year. These requirements call for the use of either thicker insulation (between 30-60 cm) or more innovative, thinner insulation materials with better U-values (BMWi, 2008). Passive houses are promoted by multiple means in Germany, including the KfW bank funding programmes, DENA awareness raising campaigns and demonstration projects and the "Certified Passive House Designer" training programme of the PassivHaus Institute since 2007. As of May 2008 about 8,000 dwellings have been built according to the passive house standard in Germany (Elswijk & Kaan, 2008).

Two thirds of the total funding for R&D available in Germany every year is provided by the private sector and the remaining one third is funded by the government (BBF, 2008). The IEA (2009b) estimates the total expenditure for R&D on energy efficiency in buildings at 31.6 million US dollars in 2009, which is allocated to programmes such as Future Building or Research for energy-optimised construction (BMWi, 2007 and 2009). In line with Germany's decentralized administrative structure, funding for R&D is also provided by the different states, municipalities and public-private partnerships. Private and public support for R&D have shown to be successful in pushing the best segment of the market and demonstrating new energy efficient technologies and products in the building sector.

The federal government offers several information- and advisory services to consumers stimulate the interest for energy efficient buildings; including DENA, the German Consumer

Organisation and the Federal Office of Economics and Export Control; insulation is among the main topics addressed during these phone and on-site consultations (Verbraucherzentrale, 2010b).

Overall, information and capacity building programmes together with the updates in building codes, financial incentives and voluntary instruments are the main drivers of the improvement energy efficiency in the building stock of 15% in the period 1990-2007 (BMVBS, 2007). Financial support from KfW programmes to promote energy efficiency in existing buildings has played a very important role uptake of insulation. Of all energy related upgrades in buildings, 40% were related to insulation (BMVBS, 2007).

2.2 United Kingdom

Not before the 1980s, got Building Regulations for England and Wales[1] on the agenda to address energy efficiency issues in the building sector. Energy efficiency requirements were set in form of U-values by setting a maximum rate of heat loss for each building element (referred to as the elemental method). In the 1990s, the level of requirements for each element got more stringent (see Table 1) and an average U-value was set on the whole building envelop. Although the latter offers greater flexibility to meet the requirements through different combination of individual elements, it has also been identified as a weakness (Killip, 2005) and led to undesirable solutions such as smaller windows to increase the thermal performance of the wall surface.

Table 1: U-values for building components (1982-2016)

		Required U-values ($W/m^2,K$)					Estimated	
Revision Year		1982	1990	1994*	2002	2006	2013	2016
Building components	Walls	0.6	0.45	0.45	0.35	0.35	0.25	0.15
	Roofs	0.35	0.25	0.25	0.16	0.25	0.20	0.15
	Windows	No requirement (typically 5.6 achieved)	3.3	3.3	2.0	n/a	n/a	n/a
	Ground floors	No requirement (typically 0.6 to 0.7 achieved)	0.45	0.45	0.25	0.25	0.20	0.15

*Due to changes in the calculation method, U-values for 1994 are better in practice despite being shown as being the same as 1990 (based on Shorrok (2005) and Defra (2008)).

[1] This section focuses on the Building Regulation in England and Wales. Scotland and in Northern Ireland have different Building regulations which generally require the same standards but regulations are revised at different times.

The implementation of the European Building Directive in 2006, changed the calculation method (to Dwelling Carbon Dioxide Emission Rate, DER) and for the first time integrated air tightness and thermal-bridging into national legislation (Elswijk & Kaan, 2008). At the same time, the government launched the action plan with the target for all new buildings to move to Zero Carbon Buildings[2] in 2016 for consultation. As part of this consultation the final version of the Code for Sustainable Homes (CSH) was announced. CSH was a voluntary measure, but as of May 2008 all new homes are required to have a rating according to the code. In order to achieve code level 6 by 2016, building regulations will include a parameter equivalent to the required U-value for the passive house standard of 15 kWh/m^2/year (Elswijk & Kaan, 2008). Accordingly, insulation levels will be required to increase in order to meet these ambitious targets (CLG, 2007). Between 1965 and 2005, energy efficiency requirements of building regulations have contributed to reducing the energy consumption of an average new dwelling by about two thirds (see Figure 3). Experience shows that over time the insulation requirements for new buildings have also been adopted in the renovation of the existing building stock (Shorrock, 2005).

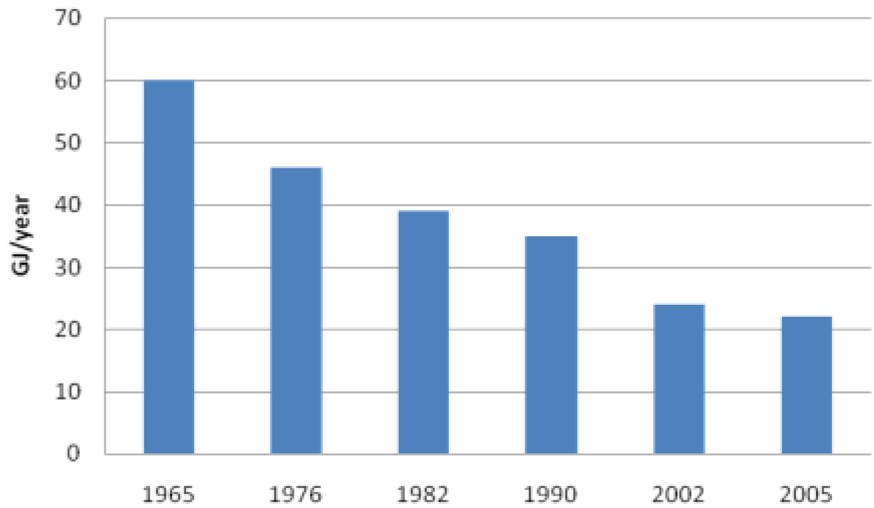

Figure 3: Energy consumption in an average dwelling according to building standards (based on Shorrock, 2005)

[2] Zero carbon buildings can be generally defined as “buildings that over a year do not use energy that entails carbon dioxide emission. Over the year, these buildings are carbon neutral or positive in the term that they produce enough CO2 free energy to supply themselves with energy” (IEA, 2008a, p.71).

Government grants for energy efficiency upgrades in existing homes have been available since 1978 in different schemes with different target groups and have played a very important role in increasing the insulation uptake in the UK existing building stock. During the Home Insulation Scheme (1978-1990) providing grants for loft insulation and hot water tank lagging, the uptake of insulation increased rapidly (Shorrock & Utley, 2003). The Energy Efficiency Standards of Performance (1994-2002), the Energy Efficiency Commitments (EEC1 and EEC2) between 2002-2008 and the Carbon Emissions Reduction Target (CERT) from 2008 programmes have been targeting energy suppliers to provide energy efficiency measures to their customers in the residential sector. The EEC and CERT have been running for about 15 years, the level of targets energy suppliers were required to meet have been set more stringent in the different programmes. The majority of targets has seen and expected to be achieved through insulation measures (see Figure 4). The Landlords' Energy Saving Allowance, introduced in 2004 and extended to 2015, is a tax allowance of landlords to improve the energy efficiency of the residential properties they rent and on their tax return claim the cost of buying and installing energy saving measures. The Value Added Tax (VAT) was reduced from 17.5 % to 5 % for energy saving materials and for insulation installations to encourage investments in household energy efficiency; it is the lowest VAT rate allowed under EU agreements.

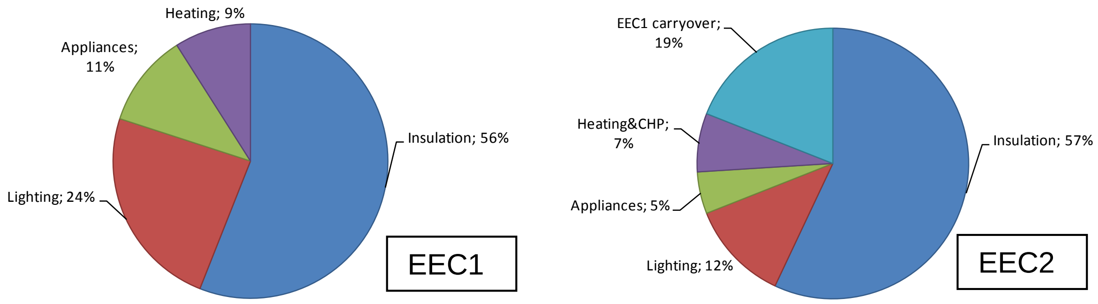

Figure 4: Energy saving measures delivered under ECC1 and ECC2 (2002-2005 and 2005-2008) (based on Ofgem 2005 and 2008)

The Pay As You Save (PAYS) scheme addresses energy efficiency retrofitting by subsidizing upfront costs and financing repayments with the savings made as a result of the implementation of energy saving measures (UK Green Building Council, 2009). This concept is a result of a collaborative effort facilitated by the UK Green Building Council and lead by Knauf Insulation.

R&D expenditures on energy efficiency in buildings in the UK are well below the R&D efforts of other OECD countries such as Germany, Japan, France and Italy in this field. IEA (2009b) estimates the total expenditure for R&D in the UK (which among other categories includes new insulation and building materials as well as thermal performance of buildings) at 8.2 million US dollars in 2008. In addition, there is no single authority with overall responsibilities over R&D energy programmes. The Office of Science and Innovation (OSI) of the Department of Trade and Industry, often in collaboration with the Building Research Establishment (BRE), has a key role in providing coherence in the implementation of energy research policy and programmes. Like in many other countries, R&D efforts need to be significantly scaled up to address the full energy saving potential of energy efficiency measures in the UK building stock (Ecofys, 2008).
Information and capacity building programmes have been very intensive in the past few years. The ones with national scope have been mostly managed by the Energy Saving Trust (EST) or the Building Research Establishment (BRE).
Energy efficiency advice on energy related issues for households are also promoted through more than fifty local information centres (Energy Efficiency Advice Centres); this network was set up in 1994. The BRE runs an information programme on passive houses (PassivHausUK) including PassivHaus design concepts, certification services and practical information (BRE, 2009a). Efforts up to date regarding information and capacity building programmes are not considered to be enough to properly support the implementation of building codes and grants for energy efficiency measures (IEA, 2008b).

2.3 Sweden

Policy intervention for improved insulation in Sweden has mainly been characterized by building codes from early on and fragmented subsidies from the 1980s. Since the mid 2000s, voluntary approaches have started to emerge, such as the passive house initiative which will supposedly lead to the wide spread of improved insulation technologies.
The first building codes of the 1940s and 1950s included mainly safety and quality standards for insulation materials and training for installers. Energy efficiency requirements however were not included until 1960. BABS 1960 set requirements on the quality of insulation in terms of minimum insulation thickness and the performance of the insulation material. This was the first milestone that triggered improved insulations in buildings. It also required the classification of mineral wool materials according to their lambda-value, i.e. energy performance. Later, BABS 1967 included concrete requirements (U-values) for individual building components in specific temperature, differentiating also between walls with heavy (0.4 W/m^{2}K) and light (0.8 W/m^{2}K) wall constructions. In SBN75, the obligations were

strengthened; the U-values were set 0.25-0.30 W/m^{2}K depending on the climate zone. In the 1980s, the building codes were modified and in 1984 the U-value for walls in two climate zones changed to 0.17 W/m^{2}K. SBN88, aimed at supporting system solutions instead of setting requirements on individual building components. The compulsion for an average U-value on the whole building envelope was formulated, which allowed more flexible solutions in the construction. In 2002, based on the European directive on Building Performance (2002/91/EC), Sweden issued a new building code in 2006 and introduced an energy declaration program in 2009. The Swedish building code BBR12 set minimum standards on the energy performance of new buildings as well as it set requirements for the whole building envelop without specifications on e.g. cavity wall insulation performance, as an alternative demand for smaller residential buildings it suggests an U-value of 0.18 W/m^{2}K for cavity wall insulation in new constructions (BBR12, 2006). The latest update of the building code (BBR16, 2009) has not changed the specific requirements on individual building components, but revised the required level of energy demand in different climate zones and extended the two to three zones.

Table 2: U-values for building components in Sweden (1967-2010)
(based on sources BABS1967, SBN1975, SBN88, BBR9, BBR10, BBR12, BBR16)

		Required U-values (W/m^2,K)						
Revision Year		1967	1975	1980	1988	2002	2002	2006****
Building components	Walls	0.40-0.80*	0.25	0.25	$U_{m,krav}$=0.18+0.95(A_f/A_{om}) average U-value A_f=window area (m^2) A_{om}=total area (m^2)	$U_{m,krav}$=0.16+0.81(A_f/A_{om}) average U-value A_f=window area (m^2) A_{om}=total area (m^2)	$F_s = \frac{\sum_{i=1}^{n} U_{just,i} \times A_i + \sum_{k=1}^{m} l_k \times \psi_k + \sum_{j=1}^{p} X_j}{A_{om}}$	0.18
	Roofs	0.35-40	0.17	0.17				0.13
	Windows	2.1-2.7**	2.0	2.0				1.3
	Ground floors	0.40	0.30	0.30				0.15

* 0.40 for light construction (< 100kg/m^2) and 0.8 for heavy construction, such as brick walls
** 2.1 when the window area is ≥60% of the wall area and 2.7 when window area is ≤60%
*** See detailed explanation for the calculation method in BBR10
****Besides the calculation method for average U-values and the energy demand distinguished in three climate zones, there is alternative requirements for the building components in small family houses

Besides regulations, the diffusion of energy efficient products was supported by various short-term subsidies. The first subsidies were provided as short-period governmental loans given to newly built family-houses in the mid 1950s after the Suez-crisis. Due to the loan improved insulation was installed. In 1975, in parallel with SBN75, the Swedish government, provided large tax exemptions for (amongst others) refurbishment of existing house stock (SFS 1974:946). The tax relief was first set for a period of two years and was then prolonged with two to three years at the time, with short breaks in the 1990s, until 1999. The tax exemption program was re-initiated in the 2004 with a time frame of two years at a time. The tax exemption did, however, not have any requirements on the performance level of insulation or installation work.

In 2007, based on the voluntary passive house standard in Germany, a passive house specification was issued in Sweden, which was then revised in 2009 (Energimyndigheten, 2009). These houses require having insulation with U-values around 0.1 W/m^2K. To reach these thermal insulation qualities, either 30-60cm thick insulation or high performance thin layered insulating material is required. Although, the share of low energy houses is very low on the market, with the implementation of the 2020 European directive, market actors expect more application of the above technologies.

3 Development Path

3.1 Technology Development of Mineral Wool Insulation for Buildings

The technology development of mineral wool building insulation is typically characterized by incremental changes in the production process, led by a few large insulation manufacturers on the global market.

Mineral wool, stone wool and glass wool[3], has been produced since the beginning of the 20th century. Like in many other industries, the very early production of mineral wool industry happened through trial and error back in the 1930s, rather than procedures based on scientific knowledge. This applied for instance to the search for raw materials, binder and melting techniques as well as the fiberization[4] process. Until the 1950s, different production technologies have been developed, in case of stone wool with the focus on melting

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[3] Glass wool and stone wool are interchangeable for many insulation applications. However, in general, glass wool is favored for loft insulation due to its light weight and ease of handling, good thermal insulation and low cost, whilst stone wool is preferred for applications were fire protection is important, due to its high melting point, thus higher fire resistance.

[4] The molten glass is led through a series of channels to the spinning area where the glass flows by gravity into a rapidly rotating spinning device with fine holes; passing through the spinner it get converted into fibers.

techniques and for glass wool mainly on the fiberization process. The production process got industrialized in the 1950-60s (Öhberg, 1987) and R&D has been continuously targeting the manufacturing process since then. R&D activities in the insulation industry have historically been driven by insulation manufacturers with no support from governments. In the 1980s, R&D was geared towards the improvement of customer service with patents on innovative packaging which considerable improved logistics. While since the mid 1990s, energy efficiency improvements with focus on energy and raw material use have been a common initiative among mineral wool manufacturers mainly driven by cost savings and the market competitiveness. Large mineral wool manufacturers have been generally very patent active. Saint Gobain Isover claims to register a dozen patents each year to improve the thermal performance of their mineral wool products which has resulted in a 25% improvement in the thermal performance of glass wool over the last 10 years (Saint Gobain Isover, 2008c). Alongside the continued innovation efforts in the development of new products and improved production processes, there has been a trend in the last decade to investigate overall energy efficient solutions in buildings according to a system approach. Following the passive house concept, Saint Gobain Isover launched the "Multi-Comfort Home" concept in 2006 which combines high thermal insulation standards with other energy efficient measures.

Due to the above described incremental technical changes, the thermal performance of mineral wool products have been gradually improving. According to the interviewed manufacturers, thermal conductivity values for mineral wool products have been improved since the 1970s from lambda values[5] of 0.045 (W/mK) to the current 0.032 (W/mK) for glass wool products and 0.035 (W/mK) for stone wool. With these improvements alone, it would not possible to achieve energy efficiency levels in buildings which are required in regulation. As a consequence, thickness of insulation products has increased in order to achieve a specific thermal resistance, as it is much cheaper to increase product thickness than it is to use a product with a lower thermal conductivity. See Figure 5 for the development of thickness of insulation in different European countries.

[5] The thermal conductivity or lambda value measures a material's ability to transmit heat at a given thickness measured in as the heat amount in Watt per hour passing through a 1m thick layer with a difference in temperature across the material of 1 Kelvin (or 1°C). The unit is simplified as W/mK.

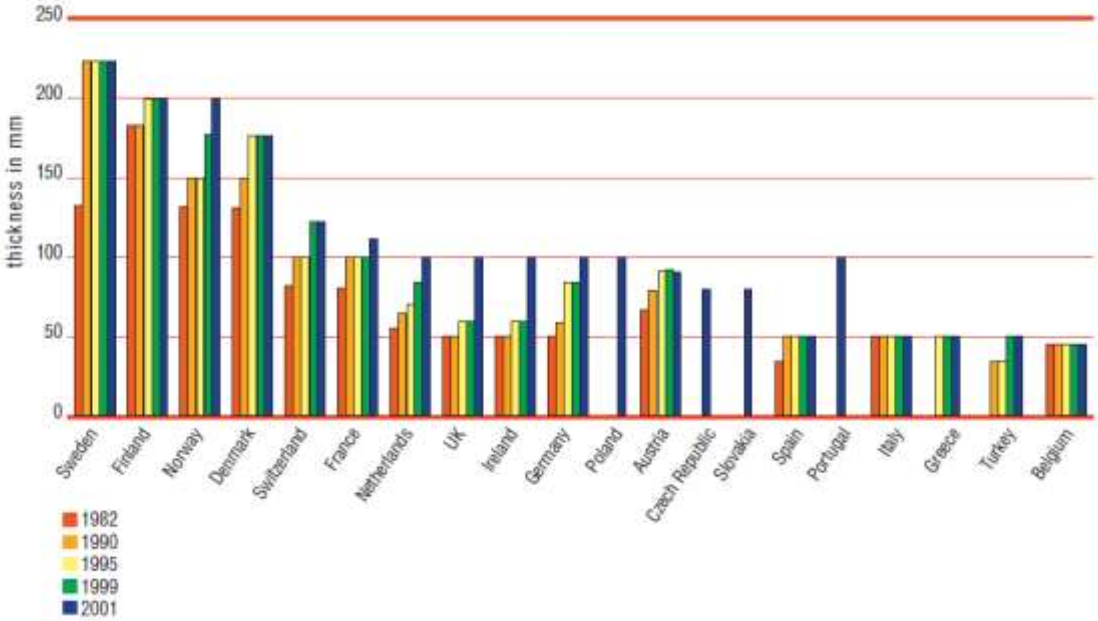

Figure 5: Insulation thickness in walls – Europe (1982-2001)
(based on Ecofys, 2002 and Eurima, 2010)

Today, the two market trends in terms of thermal performance are (1) increasing insulation thickness of “lower” performing insulation products and (2) the development of higher performing insulation products mainly in the context of low energy building standards. The second trend has only been visible in the market since around 2000. The demand for higher performing insulation products is expected to rise as the market share of passive houses and other types of low energy buildings increases. Due to the currently limited market share of low energy buildings, no substantial changes are expected in terms of the diffusion of higher performing insulation products in the short term. Based on interviews, it can also be stated that no fundamental changes in the thermal conductivity values are expected in the years to come. New combinations of materials that overall have a better performance might be found but for single products only little improvements can be expected as mineral wool manufacturers are getting closer and closer to the threshold after which substantial improvements in the thermal performance of their products are not economically feasible.
As a result of the periodic strengthening of building codes since 1965, insulation thickness has grown steadily. The approximated thickness for a typical glass wool product required by building regulations for new buildings during 1965-2003 is illustrated in Figure 6.

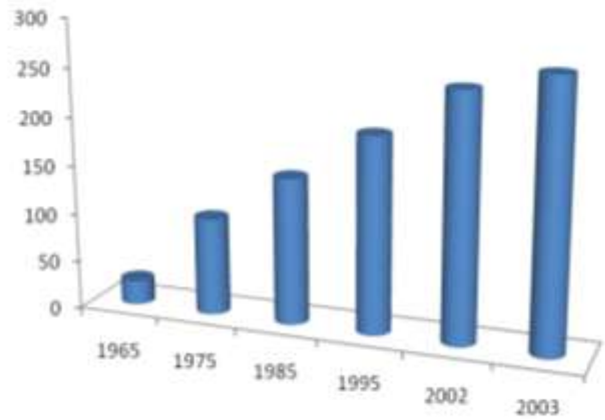

Figure 6: Approximated thickness of a typical glass wool product for cold roof application in the UK (based on MacDonald, 2004)

3.2 Development of Knowledge

Mineral wool insulation products have been in the market for about a century. In the early 1900s, the focus was on developing fiberization technologies, thus searching for finer fibers with improved properties and performances. Since the 1950s the basic process however has remained unchanged, nevertheless, thermal conductivities of insulation products have undergone gradual improvements and the thermal performance of mineral wool products has improved for about 30% since the 1970s. The search for better performing thermal insulation products has been present and has greatly supported learning-by-searching.

Many R&D efforts have been directed to provide insulation solutions for an increasing number of end-use applications which has also contributed to the improvement in the thermal conductivity of mineral wool insulation products. In the past 10 years, R&D efforts for products with higher thermal performance have been triggered by the role of insulation in different standards for low energy buildings such as the German passive house standard. This type of buildings has special requirements for insulation that are driving the search for materials with lower thermal conductivity. In the UK, the same market trend can be observed due to the promotion of zero carbon buildings. For cavity wall insulation, there is limit to the width of the insulation layer and thinner insulation materials are needed.

R&D results of insulation manufacturers are generally protected by patents. As a result the industry has high technical & know-how related barriers. Specific know-how is needed to produce mineral wool according to the current norms. The production of glass wool for instance requires knowledge on advanced chemistry of glass to be able to successfully formulate certain glass compositions that are needed in the manufacturing process. In addition, there are considerable financial barriers. The setting up of an insulation production facility is very capital intensive. For a newcomer, it is very difficult to overcome these technical and know-how related barriers which is why the way to enter the business is by acquiring existing operations. Despite the fact that these entry barriers and related patents have to some extent possibly prevented knowledge from being transferred, the possibility of receiving property rights for research has definitely been an incentive for companies to invest in R&D and has enormously facilitated learning-by-searching.

Interviews indicate that the feedback loop is intense in the insulation industry. Feedback is received on products through all the channels used by insulation manufacturers to communicate with customers groups and architects: (1) sales department of insulation manufacturers, (2) the information exchange which occurs when customers contact technical support lines with a specific inquiry on a specific product, (3) training sessions and events organized by insulation manufacturers. This information exchange is lead by insulation manufacturers who provide information on their products to their distributors for them to be able to inform to their customers (e.g. architects or construction firms) as well to installers and DIY (do-it-yourself) users to guide them on the correct installation of their products. Nevertheless, the information exchange is not equal in both directions and more information seems to be flowing from insulation manufacturers. In the case of installers for instance, feedback on products is usually limited to the quality of products on issues such as if products are easy to install and the quality of the packaging. Architects are approached on seminars, which are typically organized on topics related to the use of insulation products in the context of new building regulations.

In the last three to four years there has been an increase in sales going through DIY stores, driven by increasing energy prices and the availability of governmental incentives for the energy efficient upgrading of buildings which has driven a higher demand for renovation activity particularly in the UK. The installation of DIY loft insulation has been increasingly carried out by homeowners or small installer companies who purchase materials for loft insulation from DIY stores. Manufacturers are proactively adapting their product range to be more suitable for DIY users mainly by making them easier to handle and to install and generally more user friendly. Insulation manufacturers have intensified their interaction with user groups which has allowed for a certain involvement of user in the product development. On the other hand the involvement of users in product development has continued to be hindered by the fragmentation of the supply chain of insulation products and the highly unilateral character of the interaction between insulation manufacturers and user groups, which drastically slows down the processes of continuous learning-by-using.

3.3 Access to Resources

There has been no significant government investment for the development of mineral wool insulation products. Resources for R&D have been almost entirely provided by the private sector. Driven by the opportunity to increase the competitive advantage, mineral insulation manufacturers have heavily invested in R&D to improve the thermal performance of products. Interviews indicate that R&D has always been the priority of the insulation industry and in general has partly been driven by the gradually strengthened building codes. Another driver historically pushing for private R&D efforts has been the competitiveness of the market, also due to increasing energy prices. These factors extremely supported learning-by-searching.

Besides the access of private capital, the availability of time for learning has been very important for the development of the insulation industry. Mineral wool manufacturers have more than 50 years of manufacturing expertise. The production process for mineral wool was industrialized around the 1960s. The production processes has improved with time and there has been an increase in production capacity and consequently more know-how. Fixed costs are significant in the mineral wool industry and consequently, high plant utilisation is essential to achieve profitability. It can be therefore assumed that high production rates have been achieved. Consequently, it can be concluded that conditions for learning-by-doing have been present and highly supported for decades.

3.4 Development of Markets

The mineral wool market has a concentrated supply structure; it represents 60% of the European market and is dominated by a few producers worldwide supplying the varying national demands. There are three main factors affecting the demand for insulation materials: (1) activity in the construction sector, (2) increasing energy prices and climate change concerns and (3) policy intervention to address energy saving potentials in the building sector.

Volatility of energy prices and increasing concern over climate have driven increasingly stringent legislation that prescribes higher levels of energy efficiency and comfort in buildings, which has led to more insulation materials being applied. This has been the main factor in driving the demand of insulation products since the 1970s. The first building codes specifically addressing energy efficiency requirements and setting maximum U-values for building components were adopted as a reaction to the oil crisis in the 1970s. Increasing energy prices also triggered other R&D efforts, in addition to the search for products with higher thermal performance, towards reducing energy use in several life-cycle stages of insulation products. Examples include the significant energy savings have been achieved by means of the development of more energy efficient packaging solutions and the improvement of thickness recovery. In this context it can be concluded that changing circumstances and increasing energy prices has significantly facilitated learning-by-searching.

In general, the construction sector in European countries, experienced uninterrupted growth from the end of 1990s until the end of 2000 (Gluch, 2009). In the three selected countries, the total renovation market (including repair & maintenance in the residential sector as well as other public and private repair & maintenance work) represents the largest sector in terms of building thermal insulation sales, while the new build residential market represents less, but often times higher quality insulation technology demand. In the UK, retrofit loft and cavity wall insulation applications have increased strongly in recent years as demand has been generated through the government's EEC/CERT programme in the period 2002-2008. In Germany, only about 2% of the building stock is currently renovated every year and the new build sector is the lowest in Western Europe. As a result, the demand for insulation materials has slightly decreased since 2003 and is not expected to increase in the short term. In Sweden, renovation of the 1960s house stock is an emerging, whereby the industry is expecting signals from authorities for re-enforcement to implement improved insulation standards.

Since the 1970s the overall quantity of all insulation products sold has significantly risen building regulations and governmental programmes have driven up the greater use of insulation materials. While Sweden experienced a fairly constant market share of mineral wool products, in Germany and the UK, the market share of mineral wool has been slightly decreasing in recent years. It is due to the increasing share in EPS (expanded polystyrene) products in Germany and PUR/PIR (polyisocyanurate/polyurethane) insulation products in the UK. Mineral wool is sold on thickness rather than thermal performance. This makes PUR/PIR insulation products more attractive as they can achieve the same thermal resistance as mineral wool with thinner insulation layers. Mineral wool insulation, however, is one of the materials with a higher sustainability performance according to the Green Guide to Specification, which assesses the sustainability performance of construction materials based on their environmental impact over their life cycle, whereas PUR/PIR insulation materials have a lower rating. In addition, the market share of PUR/PIR insulation may decline in the future due to increasing costs as market prices for PUR/PIR are linked to oil prices (Dunn-Meynell, 2009).

Market development has been observed from the insulation products users´ perspective and the presence and intensity of the conditions for learning-by-using has been assessed. It was found that insulation manufacturers are in direct business contact with three customer groups: (1) intermediaries (distributors, building merchants or specialists) that sell their product either to smaller merchants or to construction companies, (2) DIY stores and (3) installers. The large majority of the products are sold through distributors, building merchants or specialists. This structure has been fairly stable over time. In this highly fragmented supply chain of insulation products, insulation manufacturers are not in direct contact with end users (e.g. homeowners) and therefore there is no opportunity for learning-by-using to happen in that sense. To achieve the highest energy potential offered by insulation measures, installers are very important as the quality of their work determines to a high extent how much energy is ultimately saved by the installation of insulation products. In addition, they are the key link in the supply chain to reach end users. Moreover, the interaction with architects and construction firms is paramount as they are responsible for the choice of insulation materials. In this regard, the interaction with architects and building companies who could transfer the demands of end-user to insulation manufacturers could theoretically provide a platform for learning-by-using.

Insulation manufacturers have communication channels in place to receive specific demands and feedback from customer groups, architects and construction firms on the use of their products. However, it seems more targeted, regular and systematic procedures are needed to be able to collect more systematic feedback particularly from architects, construction firms and installers which would support learning-by-using to a much larger extent. More efforts are very likely to be expected from insulation manufacturers in the years to come especially if these actors become more proactive in setting increasing demands for energy efficiency.

3.5 Development of Actors and Networking

There has been an increasing mutual interest of actors involved in insulation products to collaborate and exchange information and knowledge, these initiatives as well as awareness raising originated from insulation manufacturers and have become more frequent in the last decade in all three countries. Several types of trainings have been offered amongst others to insulation installers, which created a very important platform for learning-by-using. However, interaction with architects, an essential actor group in the decision making process, has been more challenging and thus limited over time. European initiatives, such as the building directive and environmental product declaration have provided increasing support for learning-by-interacting.

The last decade has been characterized by more dialogues and collaborative projects. Mineral wool manufacturers have increasingly participated in initiatives that promote better design of buildings with different project partners including universities, architects and construction firms. The collaboration around projects on the development of passive houses and other low or zero carbon building standards has been a recent development which has driven collaboration between insulation manufacturers and other building professionals. The majority of mineral wool producers is involved in such projects and has developed insulation solutions for low energy buildings (passive houses, low or zero carbon buildings, etc.). This type of cooperation with actors upstream the value chain such as designers, developers and construction companies is happening on a project basis and is far less frequent and intense than with those actors with whom insulation manufacturers have a direct business connection.

Insulation manufacturers have an ongoing dialogue with other producers at the different national and European associations. They work together to highlight the importance of insulation and its impact on the overall energy performance of buildings. The main tools are awareness raising activities very frequently based on conducting research on the benefits of insulation usually in the context of an advocacy exercise to influence legislation. This information exchange is largely limited to policy development since manufacturers do not share information on technological issues. In addition to promoting energy efficiency in buildings, one of the latest trends has been the promotion of sustainability in construction. Several producers are currently promoting Environmental Product Declarations (EPDs) as the most suitable life-cycle approach to assessing the impacts of products from an environmental, social and economical point of view. Participation of insulation manufacturers on European policy development mainly through their European Associations has significantly increased since the introduction of the EPBD in 2002.

Manufacturers offer training and awareness raising activities for their main customer groups and architects. Training and networking activities have generally intensified in the last 10 to 15 years due to growing mutual interest. In the case of installers, interaction is usually initiated by insulation manufacturers. Mutual interest has been increasing over the years particularly in the case where manufacturers establish closer collaboration mechanisms such as a list of approved installers for their products. Distributors are generally more difficult to influence due to the amount of information they receive from other manufacturers. All producers send a considerable amount of information materials and trainings to promote their materials. As a result, distributors deal on average with about 30.000 building products. The fact that two thirds of the products used to build a house have not been in the market for more than six years shows the difficulty for architects and builders to keep up to date with the new developments of all building related products.

The presence of information asymmetries due to the highly fragmented nature of the building supply chain is one of the market barriers that are hindering more transparency and a better flow of information in the market and ultimately a wider uptake of energy efficiency measures. Policy makers have addressed this issue together with other market barriers such as difficulty in accessing capital, the presence of information asymmetries, and the split incentives issue and can be therefore considered to be intermediaries that can influence all actors in the building supply chain. The major policy initiative in the building sector has been the adoption of the Energy Performance of Buildings Directive in 2002. The EPBD obliges Member States to establish methodologies, requirements as well as inspection and certification schemes to rate the energy performance of buildings taking a holistic approach. The discussion around the implementation of these provisions in each member state has brought the issue of energy efficiency of buildings to national political agendas and has provided a holistic framework for the industry. As a consequence, there has been a shift from focusing on each actor's area of expertise to the obligation of finding common solutions for the improvement of the overall energy efficiency of buildings thereby providing an incentive for learning-by-interacting.

Other polices have had a similar effect of fostering collaboration and thereby facilitating the interaction among building professionals. There are at the moment several initiatives which are either ongoing or in preparation at the EU level affecting the construction industry that could potentially lead to influential information and voluntary measures (e.g. labelling initiatives). Insulation manufacturers for instance are working with other actors in the building supply chain in the development of Environmental Product Declarations (EPDs). This type of interaction has been intensified in the last few years due to the increasing amount of mandatory and voluntary initiatives during this period.

Trainings are offered to installers, intermediaries and architects using a variety of tools that include classroom training and e-learning. A wide range of topics are addressed including specific trainings on energy efficiency which typically focuses on (1) how to better install and chose the right product for the right application, (2) awareness raising on the fact that good insulation in the building shell is a prerequisite for energy efficient buildings and (3) how to avoid thermal bridges. Manufacturers also provide trainings to installers and architects on new regulatory requirements in each country where they are present. In EU member states, the wave created in the market by the transposition of the EPBD and the introduction of the energy performance certificates was used by insulation manufacturers in order to raise awareness on improved energy efficiency in buildings and the role of insulation. In Germany and Sweden for instance training related to energy performance certificates has been offered since the mid 2000s, the national implementation of the EPBD. The degree of the collaboration between both actors differs from manufacturer to manufacturer. Some producers have a closer relationship with a number of a list of approved contractors that are recommended to install their products. Other manufacturers train and certify installers and conduct audits and unplanned checks.

4 Concluding Remarks

Different policy instruments have been supporting the development and diffusion of more improved insulation to a different extent in the three selected countries. National building codes set the first stringent requirements for the minimum performance level, in Sweden already in the 1960s, and created market demand and diffusion early on. Financial incentives became a stringent stimulus from the 1980s, although without clear energy efficiency requirements and with short-term perspective, mainly promoting thicker, but not necessarily more advanced insulation materials. Learning processes, such as learning-by-searching and learning-by-doing were mostly happening internally in the industry until the end of 1990s. European initiatives, the European building directive and voluntary measures of the 2000s, such as passive house standards and zero carbon homes, opened the window of opportunity for more intense networking, collaboration and training activities and the development and use of high performing products, supporting processes of learning-by-searching and learning-by-interacting.

Learning-by-searching has been mainly supported by building codes. The combination of increasing volatility of energy prices and the stepwise tightening of building codes since the 1960s has driven the uptake of insulation which has been evident in the steady increase of insulation thickness. In addition, building codes have clearly supported learning-by-searching in the insulation industry by pushing for the development of higher performing insulation products. These trends have also been noticeable in the German market after the implementation of the 2005 revision of the German Energy Saving Ordinance (EnEV 2005) which already included most of the provisions of the EPBD. The percentage of higher performing glass wool insulation products, defined as those products with a lambda value of 0.035, grew from 38,7% in 2005 to 45% in 2008. The fact that the strengthening of building codes has been announced in advance has proven to be positive as it gives the industry certainty on the regulatory framework and enough time to plan potential R&D investments.

Learning-by-doing. As a consequence of the implementation of successive revisions of building regulations, production capacity of mineral wool manufacturers has increased since the 1970s. More recently, the implementation of governmental programmes providing financial incentives for the uptake of insulation in existing buildings in the UK. Much of the growth observed in the renovation market in the period 2005-2009 is due to the demand generated through the government's EEC/CERT programme. Nevertheless, the impact of building codes over the last decades has been much more significant in supporting learning-by-doing as this learning process is more likely to have happened at earlier stages of the development of mineral wool production technology between in the 1950s and 1990.

Learning-by-using is generally hindered by the fragmentation of the building supply chain and the distance between insulation manufacturers and end-users. The interaction with other important actors such as distributors, architects and construction firms and installers which are in direct contact with insulation products has been analyzed and it was found that the EPBD has been an eye opener for the building industry in terms of the need to start cooperating to provide solutions to improve the performance level of the whole building which require the integration of the different technologies. The implementation of the EPBD and successive revisions of building codes has triggered cooperation between insulation manufacturers and users groups mainly in the form of trainings offered by insulation manufacturers on the use of insulation to meet new regulatory requirements. These trainings have become more frequent over the last 10 years and are important platforms for learning-by-using. In addition, the availability of financial incentives in the form of grants for the installation of insulation, mainly in the UK, have increased the sales of insulation manufacturers through DIY stores and indirectly triggered the consideration of the needs of DIY users by insulation manufacturers. The promotion of projects around low energy building standards has triggered new requirements for insulation manufacturers. Architects and designers have expressed a strong interest in materials with lower thermal conductivity which requires less insulation thickness to achieve the ambitious U-values in passive or low energy buildings. Although the impact for the insulation industry is still low as this mainly affects wall insulation and low energy buildings still account for very low market shares, this trend is expected to intensify in the next decades.

Learning-by-interacting. The adoption of the EPBD and related policy instruments has been crucial with regards to the promotion of cooperation and mutual interest among building professionals in how to achieve overall energy efficiency in buildings. Voluntary instruments such as passive house standards have provided platform for learning-by-interacting with other building professionals which currently happens on a project basis rather than being common practice. The fact that the implementation of the recast of the EPBD forces member states to adopt a definition for very low energy standards for new and existing buildings and to ensure that all newly-constructed buildings comply with this definition by 2020, has sent a clear signal to the market and will act as strong push for learning-by-interacting. Thus, the positive effect of building codes, financial incentives and voluntary standards in bringing actors in the building supply chain together around collaborative initiatives on energy efficiency will undoubtedly increase in the next decades.

In all, this analysis provides some general policy implications on how policy incentives support learning and technology change. The experiences show that a mix of policy instruments is needed in order to address the full energy saving potential of new and existing buildings. The periodic tightening of energy efficiency requirements in building codes and financial incentives have been the most influential in improving insulation levels. Low energy building standards have an important role in providing signal and guidance to the building industry for future action.

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