Challenges and Opportunities of the Passive House Concept for Retrofit

Mlecnik, E.
Research Institute OTB, Delft University of Technology, The Netherlands and Passiefhuis-Platform vzw (PHP), Belgium
(email: E.mlecnik@tudelft.nl)

Abstract

For newly built houses and renovations European and national ambitions prescribe increasing levels of energy performances, even including achieving the passive house standard, net zero energy or carbon neutral houses. For highly energy-efficient renovation, project information from first demonstration projects is now becoming available. This paper examines experiences of demonstration projects with improved energy performance, in order to diffuse these experiences to reach other innovators and the early adopter market. Innovation diffusion theory is used to analyse examples of residential renovations using passive house technologies. Further the paper examines challenges and opportunities for the diffusion of demonstrated solutions to an early adopter market. Detailed case studies show that passive house retrofit, as well as low energy retrofit, need more holistic approaches, higher skill competence and strong process coordination. The results show that it is technically feasible to reach outstanding energy performance in renovation. However, social, political and economical issues remain important barriers to reach a more substantial market share. In particular there is a need to cluster energy efficiency principles to focus on substantial energy savings. The research leads to ideas for further study of the possible role of change agencies to support substantial energy reduction in retrofit projects.

Keywords: renovation, energy efficiency, passive house, innovation diffusion, building process

1. Introduction

1.1 The urgency of energy efficiency for residential buildings

Promoting energy efficiency in the building sector is essential to achieve the goals of the United Nations Framework Convention on Climate Change and its Protocols, for example Kyoto. The eventual aim in terms of energy reduction in the building sector is to mitigate climate change, and reducing energy use in the building sector is considered to be one of the most important and affordable means to mitigate climate change (IPCC, 2007). Despite signs of improvement, Europe’s buildings are still a large energy consumer comprising 40% of final energy use and 36% of EU CO_2 emissions (ACE et al., 2009). There are considerable differences between European countries, but on average the residential stock, consisting of households, is responsible for 30% of the total final energy consumption, and proportional to the useful floor areas (Itard et al., 2008). On average, tap water and space heating are responsible for over 60% of the final energy consumption in both residential and non-residential stock (Itard and Meijer, 2008).

The Energy Performance of Buildings Directive, EPBD, also known as Directive 2002/91/EC (EC, 2002), commends Member States to install energy performance policy in the building sector with the aim of reducing energy consumption in buildings caused by heating, hot water production, lighting, cooling and ventilation. The European Parliament (EP, 2009), in its resolution of 31 January 2008, has called for strengthening the provisions of Directive 2002/91/EC, and has called at various times, on the latest occasion in its resolution on the Second Strategic Energy Review, for a 20% energy efficiency target in 2020 to be made binding. The McKinsey Global Institute (2007) has published a comprehensive cost curve for global greenhouse gas reduction measures which states that measures in the building stock are among the most profitable.

It is recommended to look beyond small energy efficiency improvements. With the current atmosphere CO_2-equivalent concentrations, not overshooting a 2 K global warming would mean reducing fossil fuel CO_2 emissions to almost zero by 2050 (Aitken et al., 2004). Member States are expected to draw up and report national plans for increasing the number of buildings of which both carbon dioxide emissions and primary energy consumption are low or equal to zero, and set targets for the minimum percentage of those buildings in 2020 (EP, 2009). The European Commission (EC, 2006) has highlighted in its "Action Plan for Energy Efficiency: Realizing the Potential", that ‘It will take the necessary steps, in collaboration with the building sector, to develop a deployment strategy for very low energy or passive houses, with a view to moving towards this type of houses as a standard in new construction in the medium term, as the appropriate technologies become commercially available.’ The document suggests that future adaptations of the Energy Performance of Buildings Directive may be extended to include ‘low energy or Passive Houses’ as a requirement, setting a target date of 2015. For many countries the passive house level is already seen as a long term political ambition level to reduce energy consumption in the building sector (Dyrbol et al., 2008; Mlecnik, 2008; Mlecnik et al., 2008). The vision of the International Energy Agency was presented at the G8 Summit in Heiligendamm: it states that zero energy buildings are possible but they are still more expensive than traditional buildings, even over the full lifetime of the building, while passive houses are becoming economically attractive because of reduced costs for heating and cooling systems (Laustsen, 2008). This means that the passive house concept, as a basis for the realization of net zero energy buildings or low carbon buildings can certainly not be neglected.

Europe obviously has the ambition to become a global leader in promoting energy efficiency. In order to bring this ambition to fruition, it is important to create the right regulatory and policy framework for industry and the design professions to provide solutions that will reduce energy consumption in Europe's building stock, and particularly in households (ACE et al., 2009).

1.2 Research question

Some countries are advanced in energy policy, have experiences with passive houses and some form of advanced energy performance criteria, and have introduced associated quality assurance schemes (PEP, 2008; Barta et al., 2009). On the other hand, many countries still regard houses with improved energy performance as an innovation. From diffusion theory, it is known that, unless some government, entrepreneurial or non-profit organization makes an innovation available at or near the location of the potential adopter, that person will not have the option to adopt in the first place (Brown, 1981; Miller, 2009). It is important to study more advanced examples and to understand how the findings can be used for further diffusion to reach a more substantial market share of houses with improved energy performance. This is especially important since support measures for the promotion of low carbon and low energy buildings such as fiscal incentives, financial instruments or reduced VAT are to be introduced in European Member States (EP, 2009).

The previous discussion highlights the importance to study already existing examples of renovations that aim towards the low energy, passive house or low carbon level. The main question in this paper is to demonstrate the experiences of the demonstration projects with improved energy performance in order to diffuse them to reach other innovators and an early adopter market.

To answer this question we look at innovation diffusion theory, and take international examples of advanced residential renovations, from the IEA SHC Task 37 and from a Belgian Federal Science Policy project, as case studies. We study those projects as an innovation within an innovation system and insights are provided in the building processes and underlying motivation. In the next paragraph a research strategy is presented applying theory of diffusion of innovations. The following section describes relevant experiences from international research. Further Belgian case studies and experiences from the viewpoint of these theoretical elements are presented. This is followed by a discussion and conclusions.

1.3 Theoretical background

The theory on the diffusion of innovation has only occasionally been applied to the diffusion of demonstration projects (van Hal, 2007). When delving into diffusion research, it appears that there are many different views on this subject. According to Lawrence Brown (Brown, 1981; Miller, 2009), four broad perspectives can be distinguished, each of which with a slightly different take on the matter. Three perspectives explain diffusion by focusing respectively on economic improvement, affordability or communication. The latter perspective is the most popular and defines diffusion as the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003).

Advanced renovation projects with improved energy efficiency are currently experimented with on a limited basis in many countries. The following paragraph describes the availability of an innovation segment based on international research: we define the associated principles and technologies for passive house retrofit and discuss the importance of building typologies and change agents. Further, we examine our research question in detail on two case studies, from the communication perspective. Rogers (2003) defines five perceived attributes of an innovation, which can help explain the rate of adoption of an innovation: relative advantage, complexity, trialability, observability and compatibility. We shall take these attributes as a leading guideline throughout the description of the case studies. Learning-by-doing provides insights into the elements that are important considering these attributes.

2. IEA SHC Task 37

The Task 37 of the Solar Heating & Cooling Programme of the International Energy Agency (IEA SHC Task 37) showed that passive house principles and components have been successfully introduced in the retrofitting of existing buildings. For low energy housing retrofit the clustered passive house principles tend to take a more important lead than the strict passive house definition (as defined in: PEP, 2008). These retrofit principles address the minimisation of transmission and ventilation losses, passive and active solar energy, efficient energy supply and overheating control. Following these principles, technologies can be observed in demonstration projects in a clustered way. For example, building systems can include high insulation thickness, triple glazing, special insulated frames and doors, solutions for thermal bridges and building air tightness. Ventilation and heating systems are calculated and adapted to include not only heat recovery and their own energy efficiency, but also domestic hot water production, internal heat gains, passive solar gains, overheating control, passive cooling systems and shading, active systems like thermal collectors or PV-systems.

From the IEA SHC Task 37 research work it is shown that the clustering of these principles into an integrated concept leads to substantial energy reduction. The demonstration projects show that advanced renovation can reduce the energy demand to a level where energy for heating is almost not needed. Twelve Task 37 demonstration projects show energy reductions from 62 to 95% for space heating and domestic hot water, average 75%.

IEA SHC Task 37 demonstration projects that for different pre-war building typologies, the passive house standard of 15 kWh/ m^2a, although easily implemented in new constructions, is sometimes difficult to achieve in a cost-efficient way for retrofit. Especially protected facades, existing thermal bridges and highly valued ornaments are difficult to tackle. On the other side, projects in different countries demonstrate that passive house retrofits can be economically feasible for some building types (E-retrofit-kit, 2008). For typical post-war large block social housing building types, measured energy savings varied between 75 to 95% (IEA SHC Task 37). The specific heating demand is typically reduced from values between 150 and 280 kWh/m²a to less than 30 kWh/m²a. In some cases, pre-defined energy consumption for heating of 15 kWh/m²a is reached. From the technological point of view, a large group of building typologies from the sixties and seventies can relatively easy be transformed into passive houses. Especially prefabrication technologies are considered to have a high potential for advanced housing retrofit of many building typologies, since prefabricated elements allow placement in a limited time frame without hindering occupants too much (IEA ECBCS Annex 50).

The IEA SHC Task 37 demonstration projects showed that social issues can not be neglected. Ownership and decision structures, inhabitants and their characteristics and actual groups of retrofit market players should be involved in the building process, in order to be able to reach a goal of pre-defined energy saving. Also, political issues like national, regional and local regulations and incentives have shown to play a major role in the development of demonstration projects or an early market of advanced housing retrofits. Many countries (IEA SHC Task 37, sub task A) observe the need for a better consumer contact with change agents: individuals who influence clients' innovation-decisions in a direction deemed desirable. For example, the Canadian experience on marketing of advanced renovation, illustrates how to build alliances and a network to increase position and market impact in the renovation sector. A leading agent can take position, spread knowledge and increase the demand within the building industry, local authorities as well as relevant media.

In the following paragraph we discuss the experiences with two Belgian case studies as an illustration of the previous comments.

3. Case studies Belgium

3.1 Innovator case: relative advantage and observability as a driver

We discuss a renovation of a 150 year old row house in the village of Eupen, Belgium, which has been studied in line with the four perspectives described above and the innovation attributes. The case is representative as a best-practice example for the Belgian situation, where the market is mainly dominated by owner-occupants. Although the case study represents the motivated 'innovator' owner-occupant, it can be observed that the main driver for implementation was not necessarily the issue energy efficiency.

The innovator's desire to build a demonstration renovation project was clearly inspired by the increased relative advantage and observability of this kind of project. Instead of only replacing the worn-out roof and glazing, the owner was driven by the desire to increase the habitable area and to add an up-to-date extension. Another major factor that played a role was an asthmatic child. He reasoned that the old convectors and damp walls would certainly give rise to dust, and lead to moisture and health problems. Therefore the owner decided in an early stage of the design process to have mechanical ventilation with filtering, up-to-date with heat recovery. The owner, an architect, further noticed that, since extension, roof and glazing had to be replaced and that the orientation of the building was suitable, the possibility to increase social prestige by opting for a passive house standard. Finally, renovation was preferred to a new built construction because of substantially lower VAT. In conclusion, the owner was driven by relative advantage, i.e. financial advantage, comfort improvement, social prestige factors. Reaching the passive house standard only asked for some minor extra measures, as a logical next step for the owner. The economical and environmental impacts were studied on completion of the project by independent researchers: this showed that the architect's intuitive option was justified for the project.

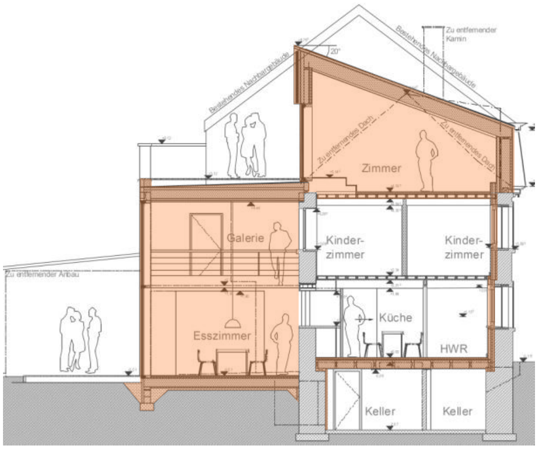

Figure 1: Case study Eupen: section of the row house in Eupen (before and after renovation, left) and detail of interior insulation, air tightness and cutting through carrier beam (right). Source: PHP, FHW architectes (IEA SHC Task 37)

The project proved to be quite a challenge in complexity, trialability and compatibility. Being the first demonstration project of a renovation towards the passive house standard in Belgium, the owner had to find all the technological solutions at regional level. In the design stage, extra care had to be taken with the evaluation and solution of thermal bridges. The city did not grant a permit to insulate the façade on the street side, so a solution for interior insulation on the front façade needed careful study and development. Providing building air tightness was a challenge, as was careful dimensioning and control of the ventilation system.

3.2 Early adopter case: wish for increased comfort leads to phased secondary energy efficiency retrofit

One of the conclusions of the Low Energy Housing Retrofit project (LEHR, 2009) was that, in order to reach Kyoto targets, the whole renovation market has to be augmented in size. For example, in the Brussels Capital Region, it is expected that the low energy renovation market has to increase from 1 to 4%. This means that not only the 'low-hanging fruit' can be addressed. Also, people who already renovated will have to be convinced to do extra building related measures to reduce energy consumption. In this framework, a second example is discussed of a renovation project in Antwerp, Belgium. This urban row house had been renovated in many phases dating back to 1911, with the last renovation in 1996. Nevertheless, the owner-occupants decided to have another renovation in 2006, although its consumption was already lower than average for the same type of building.

The cause of this decision was a perceived lack of relative advantage. It was observed by the owners that the bathroom was difficult to heat in the winter period and that its ventilation system made a lot of noise. The room below the roof was also difficult to heat in winter, it was draughty near the single-pane windows, and had a leaky roller-shutter. This gave the owners the idea to improve the thermal insulation of the roof and the rear façade. Because the owners were aware of the hassle renovation involved, they decided to have an architect do the job.

The project proved to be highly complex. It was difficult to find an architect willing to do the extra work required for the tricky connection details. The architects consulted found their relative advantage regarding cost and benefit to be low, compared with offers in new built construction. The mixed ownership of party walls posed additional social challenges to the appointed architect. On one side of the house the neighbouring owner was not interested in insulating, and on the other side the neighbour tore down a neighbouring, previously heated, space. The owners also wanted to spread the financing. The architect finally came up with a phased solution: first the roof was insulated and extended, the windows in the rear façade were replaced, and then the rear façade was then thermally insulated and plastered. Problems with damp were discovered during the process, which required several separate interventions which irritated the owner-occupants.

In general, the owners perceived a decreased relative advantage, since their main living rooms were uninhabitable for months because the contractors did not stick to the agreed time schedule. The contractors were not familiar with many of the measures taken, e.g. such as extending a roof to connect to future wall insulation, but trialability was included by learning-by-doing. The resulting project was consistent with the existing values, the required comfort and the financial needs of the adopters. As a benefit, the owners now see a decrease in gas consumption and possibilities to have income tax reduction for energy saving measures.

Figure 2: Case study Antwerp: detail of rear insulation (first, intermediate and final steps). Source: PHP, arch. G. Camerlinck; Photo: E. Mlecnik

3.3 Discussion

We discuss the factors that can influence the rate of diffusion from the experiences with the demonstration projects.

Relative advantage: What matters is not so much the 'rational' advantage of cost-efficient energy saving, but whether an individual considers an integrated retrofit project to be better than other options. The degree of relative advantage may be measured in economic terms, for example, the availability of associated financial benefits such as reduced VAT (case 1), income tax reduction or grants. Also, social prestige factors (case 1), convenience and satisfaction (case 2) are important factors. We can expect from theory that, the greater the perceived advantage of the retrofit idea, the more rapid its rate of adoption will be. We note that in both case studies improved energy efficiency was not the main driver for renovation. However, comfort improvement was. The relative advantage of the executing parties also plays a role: in case 1 the architect was motivated by his own project to increase social prestige, in case 2 it was difficult to convince an architect to do a complex job.

Complexity: Advanced retrofit projects can be perceived as difficult to understand and implement. Case 1 shows the importance of regional availability of associated technologies and the (political) barrier to insulate the front façade from the outside, leading to complex inside thermal insulation. Case 2 illustrates that a project can become complex when segmented into phases. Some barriers could be removed: for example city officials in Paris and Flemish politicians now voted a law that makes outside insulation possible. Technologies and described (phased) solutions can be made regionally available by change agents. In general, simpler solutions should be stimulated, since they will lead to more rapid adoption.

Trialability: It is important that advanced retrofit projects can be experimented with on a limited basis. Both cases now see the implemented technologies as finality. Providing the possibility for change in demonstration projects (for example industrial, flexible, dismountable solutions), and education by learning-by-doing, is necessary so that executing parties can try out solutions on a partial basis. Better trialability can improve the rate of diffusion. Documenting learning-by-doing experiences can also reduce complexity for other actors.

Observability: Observability of demonstration projects can be a major driver in the innovation phase to convince other innovators, especially when social prestige factors are involved (case 1). The easier it is for innovator-businesses to learn from a colleague-innovator demonstration project, the more likely they will adopt. Market actors perceiving good relative advantage from their involvement in demonstration projects can be expected to be proud of their project and willing to show it to other actors, so this provides an opportunity. However, the visibility will often also be determined by the availability of for example a plaque for the building, project leaflets, easily accessible internet information, media campaigns and the explicit mentioning of the associated actors and change agents in (official) listings and documentation. To convince other early adopters, peer-to-peer contacts are necessary with early adopter demonstration projects. For example case 2 had to start with a tabula rasa since no similar regional demonstration projects with owner-occupants in a similar situation were available. Observability of early-adopter motives and solutions can be improved.

Compatibility: Are the demonstration projects perceived as consistent with existing values, past experiences and needs of potential adopters? From the international research we note that for general marketing a target-group oriented approach might be more interesting than a building typology based approach. But it is also important that potential adopters can recognize their own potential projects in the building types and adopter categories demonstrated. Incompatibility will not lead to adoption unless a new value system is adopted (for example the importance of consuming less), which is a relatively slow process.

4. Conclusion

Techniques and systems for low energy housing retrofit are well developed, even for solutions with occupants remaining and with very limited time frames for renovation. A main barrier for widespread diffusion of such advanced solutions is that the European building sector is characterized by a multitude of regional market actors and different building traditions. Analyses carried out in IEA SHC Task 37 showed barriers according different types of building segments, ownership and decision processes, and national, regional and local regulations and incentives.

Generally, advanced renovation is progressing, but at a much slower rate than that needed to reach national and international goals in time. There are many reasons for this. Passive house retrofit has to compete with products where the "costs" of CO_2 emissions are not taken into account. Work in Task 37 shows that compared to ordinary renovation, passive house retrofit needs more holistic approaches, higher skill competence and stronger coordination in the planning and renovation process.

Clustering of energy efficiency principles can lead to substantial energy reduction. This opens a pathway to promote an integrated package of innovation. This provides an interesting opportunity since, according to theory, it can be expected that technology clusters can be adopted more rapidly than individual innovations (Rogers, 2003). To secure market penetration, it is important to make the market understand what the whole product consists of, per building typology, and to organize a marketplace to provide a whole product offering (Moore, 2002). Advanced renovation and increased renovation rate represent big business opportunities for proactive planners, consultants, building companies and suppliers of building components materials. So far only a few companies have seen and taken this opportunity.

In order to develop a whole system approach new political and social challenges are appearing. Resources mobilization and creation of legitimacy have to be tackled (Alkemade and Hekkert 2009).

In order to diffuse experiences from demonstration projects to a larger audience, it is important to increase the relative advantage and observability of actors involved. There is a need to showcase solutions compatible with existing building types and different target groups. Energy savings can be associated with improved comfort, citizen action, children's future,.. and should not always be reduced to money savings, as this can be counter-productive (Bartiaux, 2006). Complexity should be reduced by learning-by-doing, and subsequently providing information to other parties about the lessons learned.

In order to develop well from demonstration to volume market, one should not neglect that there is a symbiotic relationship between the existence of market infrastructure and consumer finance, both being equally important (Miller, 2009). In this framework, a specific role for change agencies seems appropriate. On a political level, the availability of a legal or instrumental framework for the introduction or diffusion of demonstration projects, and the development of the diffusion by change agents, can be stimulated. Change agencies might be the appropriate vehicle to bring more advanced retrofit into a wider practice, but then they should also address the motivations and desires of early adopter categories.

The focus in this article has been upon the process by which innovations and the conditions for adoption are made available to individuals or households, that is the supply aspect of diffusion. For future research, it can be interesting to study the activities of public or private entities through which the innovation can be distributed or made available to society at large, i.e. local diffusion agencies.

Acknowledgement

The 'Low Energy Housing Retrofit (LEHR)' project was supported by the Belgian Federal Science Policy and the research was conducted by a collaboration between PHP, BBRI and UCL – Architecture & Climat.. This paper uses material gathered in Sub Task A (work group meetings and regular skype meetings) and Sub Task C (Belgian demonstration project) of the IEA SHC Task 37. The final report of Sub Task A is currently finalized by Norway, Belgium and the Netherlands and will be entitled 'From demonstration to volume market' (due 2010).

References

ACE, COGEN Europe, EuroACE, ECEEE, Eurima, IUT, RICS (2009) *Open Letter to the 27 EU Energy and Environment Ministers*, Brussels, 2/11/2009.

Aitken D W, Bull S T, Billmann L L (2004) "The climate stabilization challenge: can renewable energy sources meet the target?", *Renewable Energy World* **7** (6) (November-December 2004).

Alkemade F, Hekkert M (2009) *Development paths for emerging innovation systems: implications for environmental innovations,* University of Utrecht, ISU Working Paper 09.08.

Barta J, Lang G, Marrecau C, Freundorfer F, Milandru A, Ekart P, Kildsgaard I (2009) *Passnett country reports on financial support schemes,* IEE Project 'Pass-net' deliverable, (available online http://www.pass-net.net, [accessed on 13/12/2009]).

Bartiaux F, et al. (2006) *Socio-technical factors influencing residential energy consumption (Serec), Part 1: Sustainable production and consumption patterns*, Scientific support plan for a sustainable development policy (SPSD II) (UCL, VITO and Danish Building Research Institute), Brussels, Belgium.

Brown L (1981) *Innovation Diffusion,* Methuen, New York.

CIB (1982) *Working with the performance approach to building,* Report of the Working Commission W60, Publication 64, CIB, Rotterdam.

Dyrbol S, Thomsen K E, Wittchen K B, Jensen O M (2008) "European shift towards very low energy buildings", *Proceedings of PassiveHouse 2008,* Brussels, Belgium, pp. 31-38.

EC (2002) *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings*.

EC (2006) European Commission Communication COM(2006)545 final, *Action Plan for Energy Efficiency: Realising the Potential,* Brussels, 19.10.2006.

EP (2009) *European Parliament legislative resolution of 23 April 2009 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2008)0780 – C6-0413/2008 – 2008/0223(COD)),* consulted: June 15, 2009; last update May 15, 2009.

E-retrofit-kit (2008) *Toolkit for Passive House Retrofit*, http://www.e-retrofit-kit.eu.

IEA ECBCS Annex 50 *Prefabricated Systems for Low Energy Renovation of Residential Buildings,* (available online http://www.empa-ren.ch/A50.htm [Ongoing]).

IEA SHC Task 37 *Advanced Housing Renovation with Solar and Conservation*, (available online http://www.iea-shc.org/task37/ [Ongoing]).

IPCC (2007) *Summary for policy makers – IPCC WG1 Fourth Assessment Report,* Paris, (available online http://www.ipcc.ch [accessed on 13/12/2009]).

Itard L, Meijer F, Vrins E, Hoiting H (2008) *Building renovation and modernization in Europe: state of the art review,* OTB, Delft University of Technology, The Netherlands, (available online www.erabuild.net [accessed on 30/12/2008]).

Itard, L, Meijer F (2008) *Towards a sustainable Northern European housing stock: Figures, facts and future*, IOS Press, The Netherlands, ISBN 978-1-58603-977-6.

Laustsen J (2008) “Roadmap to Energy Efficiency in Buildings. A Global Strategy for Energy Efficiency in Buildings, IEA Work for the G8”, *Proceedings of the 12th International Passive House Conference*, Nürnberg, Passivhaus Institut Darmstadt, Germany, pp. 43-50.

LEHR (2009), *Low Energy Housing Retrofit*, Research project supported by the Belgian Federal Science Policy, PHP/ BBRI/ UCL, Belgium, (available online www.lehr.be [accessed on 26/11/2009]).

McKinsey Global Institute (2007), The McKinsey Quarterly 2007 Number 1.

Miller D (2009) *Selling Solar. The diffusion of renewable energy in emerging markets*, Earthscan, UK.

Mlecnik E (2008) “Marketing of Passive Houses: Experiences from the Low Countries”, *Proceedings of Passivhus Norden 2008*, Trondheim, Norway, April 2-3, pp. 192-201.

Mlecnik E, Kaan H, Hodgson G (2008) “Certification of Passive Houses: a Western European Overview”, *Proceedings of PLEA 2008, 25th conference on Passive and Low Energy Architecture,* Dublin, 22-24th October, paper 106.

Moore, G A (2002), *Crossing the Chasm,* 3rd edition, HarperBusiness, New York.

PEP (2008) *Promotion of European Passive Houses*, Intelligent Energy Europe SAVE project EIE/04/030/S07.39990, (available online http://pep.ecn.nl/ [accessed on 16/11/2009]).

Rogers E M (2003) *Diffusion of innovations,* 5th edition, Free Press, New York.

van Hal J D M (2000) *Beyond the demonstration project - The diffusion of environmental innovations in housing,* PhD. Thesis Delft University of Technology, Faculty of Architecture, ISBN 90-75365-35-7.