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Essays in Economics of
Energy Efficiency in Residential Buildings -
An Empirical Analysis

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ZUSAMMENFASSUNG

Energieeffizienz im Gebäudebereich ist weltweit eines der Schlüsselemente einer kosteneffizienten Energie- und Klimaschutzpolitik, zum einen aufgrund seines beträchtlichen Anteils am globalen Energiebedarf (etwa ein Drittel) und den damit verbundenen CO₂- und weiterer Emissionen, und zum anderen aufgrund der bedeutenden technischen Potenziale, welche zum grossen Teil rentabel oder zu geringen Kosten erschliessbar sind, aus der privatwirtschaftlichen und noch viel mehr aus der volkswirtschaftlichen Perspektive. Es zeigte sich jedoch eine zunehmende Diskrepanz zwischen der Kosteneffizienz der Energieeffizienz-Investitionen, ihren potenziellen Meriten, den Notwendigkeiten aus gesellschaftlicher Sicht und der tatsächlichen Anwendung. Daraus ergab sich die Forschungsfrage, ob diese Diskrepanz, die sich in geringen Erneuerungsraten und in einem moderaten Effizienzniveau ausdrückte, empirisch tatsächlich bestätigt werden konnte und wenn ja, wie diese zu erklären und gegebenenfalls mit geeigneten Politikmassnahmen zu überwinden war.

Um diese Fragen anzugehen, war der multi-dimensionale Charakter der Wirkungen und Nutzen von Gebäude-Energiedienstleistungen (gut konditionierte Lebens- und Arbeitsräume) zu berücksichtigen. Zusatznutzen entstehen auf der gesellschaftlichen Ebene („ancillary benefits“) und auf der individuellen Ebene („co-benefits“), wobei letztere von Gebäudelabeln wie Minergie, Passivhaus und weiteren zunehmend ins Zentrum gerückt wurden. Zu Beginn der Forschungsarbeiten wurde vermutet, dass diese Nutzen ökonomisch relevant sind, wobei jedoch die empirische Evidenz dafür zu jenem Zeitpunkt weitgehend fehlte. Deshalb war es angezeigt, für diese Nutzen einen geeigneten ökonomischen Bewertungsmassstab zu entwickeln, um verzerrten Kosten-Nutzen-Analysen und Entscheiden vorzubeugen, sowohl auf der individuellen wie auf der volkswirtschaftlichen Ebene.

Vor diesem Hintergrund hatte die in dieser Arbeit präsentierte Forschung das Ziel, eine solide methodische und empirische Basis bezüglich Kosten und Nutzen von Energieeffizienz-Investitionen bei Wohngebäuden zu erarbeiten, wobei auf die ökonomische Bewertung ihrer individuellen Zusatznutzen ein besonderes Augenmerk zu richten war. Anbetrachts der langen Zeithorizonte im Gebäudesektor sollte auch der technisch-ökonomische Fortschritt mitbeachtet werden. Die Ergebnisse sollten für energie-politische Prioritätensetzungen, als Inputs für Energiemodelle und als Entscheidungsgrundlagen für Gebäudebesitzer, Bauherren und die Bauwirtschaft nützlich sein. Der Untersuchungsgegenstand wurde auf den Wohngebäudesektor der Schweiz eingegrenzt.

Es zeigte sich, dass die mittels eines techno-ökonomischen Ansatzes ermittelten Grenz- und Durchschnittskosten von Energieeffizienz-Investitionen zu weiten Teil unter oder im Bereich der Grenzkosten der (Wärme-)Energieerzeugung liegen, insbesondere unter einem langfristigen Betrachtungshorizont. Die entsprechenden Ergebnisse basieren auf technischen und wirtschaftlichen Kenndaten von weitergehenden Wärmedämmungen, verbesserten Fenstern und Lüftungs- und Heizanlagen, welche bei Lieferanten und Installationsunternehmen erhoben wurden. Viele Energieeffizienz-Investitionen sind auch aus der privatwirtschaftlichen Sicht langfristig rentabel, vor allem wenn best practice zugrunde gelegt wird. Der flache Verlauf der Kurve der summierten Kapital- und Energiekosten als Funktion zunehmender Energieeffizienz bedeutet, dass weitgehende Effizienzlevels ebenso wirtschaftlich sind wie moderate, wobei erstere jedoch einem geringeren Energiepreissisiko unterliegen.

Besonders im Bereich der weitgehenden Effizienzlevels wurden beträchtliche Variationen zwischen verschiedenen Unternehmen festgestellt, welche als Pioniermarkt- und Lernzuschläge eines sich in der frühen Entwicklung befindenden Marktsegments interpretiert wurden. Diese Unterschiede und das allgemeine Kostenniveau könnte künftig stark verringert werden, wenn solche Investitionen häufiger angewendet werden, z.B. durch deren Förderung mit geeigneten Politikinstrumenten, welche den techno-ökonomischen Fortschritt stimulieren. Der Zusammenhang zwischen sinkenden spezifischen Kosten und der kumulierten Anwendung konnte in der Tat empirisch untermauert und erstmals mittels des Erfahrungskurvenansatzes formal beschrieben werden.

Die Analyse der gesamten Nutzen von Energieeffizienzattributen aus Sicht der Gebäudenutzenden, welche thermische Behaglichkeit, konstant hohe Luftqualität, Lärmschutz, Werterhaltung und Energiepreisrisiko-Reduktion umfassen, ergab eine beträchtliche Zahlungsbereitschaft eines markanten Teils der befragten EFH-Käufer und Wohnungsmietenden, wodurch entsprechende Investitionen auch für MFH-Besitzer und für Investoren potentiell interessant werden. Die Zahlungsbereitschaftswerte, welche anhand eines Choice Experiments basierend auf geäußerten Präferenzen ermittelt wurden, sind generell höher als die Investitionskosten der entsprechenden Attribute. Dies gilt insbesondere auch für die Wohnungslüftung (welche mit geringeren Energiekosten allein nicht finanziert werden könnte).

Aufgrund der kostengünstigen Energieeffizienz-Potenziale und der namhaften Zahlungsbereitschaft für die damit verbundenen Nutzen eines beträchtlichen Teils der Befragten wäre zu erwarten, dass Besitzer und Investoren in solche Effizienzmassnahmen investieren, was jedoch nur teilweise der Fall ist. Entsprechend wurden die technischen, rechtlichen und ökonomischen Rahmenbedingungen näher untersucht. Parallel dazu wurden Gebäudebesitzer bzgl. ihrer Wahrnehmung dieser Rahmenbedingungen sowie bzgl. ihrer Motivationen und Gründe für oder gegen eine Renovation befragt. Es zeigte sich, dass nicht ein bestimmter Faktor allein die Renovationsentscheide treibt oder hemmt, sondern dass eine Reihe von Treibern und Hemmnissen bestehen, welche zudem ineinander verlinkt sind. Wenn Energieeffizienz-Investitionen getätigt werden, so geschieht dies am Ende der Lebensdauer der entsprechenden Bauteile und häufig im Zusammenhang mit einer allgemeinen Renovationstätigkeit wie Um-, Aus- und Anbauten. Persönliche Motivationen und Bewusstsein bezüglich der Notwendigkeit und der Nutzen solcher Investitionen sind mindestens so wichtig wie bestehende steuerliche Anreize, Wirtschaftlichkeit oder Finanzierungsfragen.

Aufgrund der Diskrepanz zwischen der gesamtwirtschaftlichen und der individuellen Perspektive (externe Kosten, unterschiedliche Zeithorizonte) und aufgrund von Hemmnissen lassen sich Politikmassnahmen der öffentlichen Hand rechtfertigen, dies umso mehr als dass diese mit namhaften begleitenden Nutzen verbunden sind. Aufgrund der festgestellten Vielfalt und Verflechtung der Hemmnisse sollten Politikmassnahmen auf der Basis eines Portfolio-Ansatzes ausgestaltet werden. Sie sollten die festgestellten Nutzen, welche beträchtlich sind, aufgreifen und – sehr relevant – die Bewusstseinsbildung der politischen Entscheidungsträger und der Gebäudebesitzer mit beinhalten. Vorgeschlagen wird zudem, die bestehenden Verzerrungen der rechtlichen und fiskalischen Rahmenbedingungen anzupassen, die Markttransparenz zu erhöhen, u.a. mittels geeigneter Informationsmitteln (z.B. Labeln und Zertifizierungen), welche eine Qualitätsdifferenzierung ermöglichen. Eine CO₂-Abgabe, dessen Erträge teilzweckgebunden für Unterstützungsbeiträge oder fiskalische Anreize verwendet werden, könnte ein interessanter Ansatz sein, um den techno-ökonomischen Fortschritt weiter zu beschleunigen. Solche Anreize sollten breit kommuniziert, an minimale Anforderungen gebunden und v.a. auf den Gebäudebestand fokussiert werden.

SUMMARY

Energy efficiency in the building sector is a key element of cost-effective climate change and energy policies in most countries throughout the world, firstly, because the building sector contributes to a large extent (about one third) to the world's energy demand and even more to its associated CO₂ and other emissions from fossil fuel use, and secondly, because the large efficiency potentials can be regarded as mostly cost-effective or available at low cost, from a private, but even more so from a societal point of view. However, a gap between the cost-effectiveness of energy efficiency measures, their benefits, the necessities from a societal point of view on the one hand and the actual investments in the building stock – particularly in the moment of re-investment and refurbishing – on the other hand became more and more evident. The research questions that arose against this background was whether this gap and the low energy efficiency levels and rates could be confirmed empirically and if yes, how the gap could be explained and how it could be overcome by adequate policy measures.

To address these questions, the multi-functional character of buildings (i.e. well conditioned and quiet living rooms and working space) had to be considered. Associated benefits arise on the societal level (ancillary benefits) and on the private level (co-benefits), the latter being increasingly addressed by different building labels such as Minergie, Passivehouse, and others. It was assumed that these co-benefits are of economic relevance, but empirical evidence regarding their economic value was missing. Thus, putting these benefits into an appropriate economic appraisal framework was at stake to make use of them in market information and policy instruments, preventing uninformed and biased cost benefit analyses and decisions on the private and on the societal level.

Against this background, the research presented in this PhD thesis had the goal to provide a sound empirical basis about costs and benefits of energy efficiency investments in residential buildings, with a special emphasis on the economic valuation of their co-benefits from a building user perspective (owner-occupiers, purchasers and tenants). In view of long time-horizons in the building sector, the techno-economic dynamics should also be addressed. The results should be useful for policy priority setting and design, for inputs in energy models, and for building owners, developers and builders as decision support elements. Scope of the research was the sector of new and existing residential buildings in Switzerland.

Based on price and technical data of additional insulation, improved window, ventilation and heating systems, and architectural concepts, it was found that the marginal and average costs of energy efficiency are to a large extent below or in the range of the marginal costs of energy (heat) generation, especially from a societal perspective. Many energy efficiency investments are economically viable also from a private perspective, particularly if best practice is applied and if long-term considerations are being made. The flat character of the curve of annualised capital and energy costs as a function of increasing energy efficiency levels implies that advanced energy efficiency levels are as cost-effective as low ones, having the advantage of a decreased energy price risk exposure.

In cases of advanced energy efficiency levels, large variations of costs between companies were observed which were interpreted as pioneer market and learning surcharges of a market segment being in its early development. These variations and the general cost level are very likely to decrease

in the future with increasing market shares. The empirical analysis of the past dynamics revealed a considerable techno-economic progress which formally can be described by the experience curve concept.

The analysis of the total benefits of energy efficiency attributes from the building user perspective such as increased thermal comfort, constantly high indoor air quality, protection from external noise nuisance, property value and energy price risk hedging, revealed a considerable willingness to pay of a relevant proportion of home-purchasers and tenants for these benefits, making such investments also attractive for multi-family house owners due to potentially increased rental revenues. The willingness to pay, which was estimated by a choice experiment based on stated preferences, is generally higher than the costs of implementing these attributes. Particularly this applies also to housing ventilation systems which makes them economically interesting although their costs can not be covered by energy cost savings alone.

The low-cost energy efficiency potentials and the considerable valuation of their benefits by a large proportion of the respondents would suggest that owners and housing promoters invest in energy-saving measures; this is, however, not unanimously observed. Accordingly, the technical, economic and legal conditions were analysed, investigating in parallel the owners' perceptions of these boundary conditions as well as their motivations, focussing on the renovation behaviour of single-family home-owners. It was found that not one single barrier or driver prevails, but that a multitude of reasons is hindering or triggering energy efficiency in renovation decisions. Energy efficiency investments are often undertaken at the end of the building element's lifetime and during general renovation activities. Motivations and awareness regarding the need and the benefits of such investments are at least as important as economic viability, fiscal incentives or financial issues.

Due to the discrepancy between the societal and the private perspective (e.g. external costs and benefits, different time horizons) and due to the existence of barriers, public policy activity is justified all the more so as such a promotion generates ancillary benefits. Policy instruments are necessary due to the observed barriers pursuing a portfolio approach. They should appeal the considerable benefits found and – very important – include awareness raising of policy makers and house owners. Also recommended are adjustments to the current legal and fiscal distortions, an increase of market transparency and of adequate information to allow for quality differentiation, for instance by an label and certification system. A CO₂-levy whose revenues are used partially for specific subsidies or fiscal incentives could be an adequate approach to speed up techno-economic progress. If such incentives are provided they should be broadly communicated and focussed on existing buildings conditioned to minimal requirements.

CHAPTER 1

INTRODUCTION, PROBLEM, OBJECTIVES

1.1 Introduction

Energy efficiency in the building sector is increasingly seen as a key element of cost-effective climate change and energy policies in most countries throughout the world. This prominent role is due to two factors. First, the building sector is a relevant contributor to the world's energy demand (around one third) and its associated CO₂ and other emissions. Second the technical energy efficiency potentials in the building sector are particularly high (up to 80 % for new buildings relative to the existing building stock) and these potentials are regarded as mostly cost-effective or available at low cost, at least from a societal point of view, cf. IPCC (2007) for an overview.

Necessities and potentials to reduce energy demand of buildings

In emerging countries the construction of new buildings is currently one of the major drivers of additional global energy demand and should be in the focus of policy measures aiming at damping the increase of global energy demand. In most countries of the OECD and in many other countries the stock of existing buildings is of equal relevance where the concern is to reduce the total final energy demand in spite of increasing floor area by new buildings and their energy demand. Facing the potential impacts of climate change, local air pollution and the risks of increasing and/or volatile energy prices increasing the energy efficiency in general and of buildings in particular is of vital interest for most countries.

This is particularly true for Switzerland which is endowed with very limited domestic energy resources and is highly dependent on energy imports. Switzerland also signed and ratified the Kyoto Protocol committing itself to a reduction of 8% of its greenhouse gas emissions by 2008 to 2012 relative to 1990. On the national level the CO₂ is the most relevant greenhouse gas and specific goals were stipulated by the CO₂ law by the Swiss parliament, namely an overall reduction of 10%, a reduction of 8% for mobile use and of 15% for stationary use of fossil fuels by 2010 as compared to the 1990 levels.¹ Fuels are being used stationary mainly by the industrial sector and by non-residential and residential buildings. Although no further break down of the above mentioned CO₂ mitigation goals were formulated by the law there is a consensus that the burden sharing should involve each of the sub sectors about equally in terms of relative emission reduction.

The public debate has been for long supply side-oriented and have had (and still has) a strong focus on renewable energies. In contrast many technology and policy experts point to the fact that more efficient energy use could become the largest and most profitable energy "source" and that, therefore, first priority should be given to energy efficiency measures (BFE, 1996; ATAL, 1994;

¹ To mitigate climate change on the long run emissions of industrialised countries should be reduced by about 80% of the 1990 levels up to 2050

Gantner, Hirschberg et al., 2000; Jochem, Jakob et al., 2004, and others). This is true for both industrial production processes and for the energy use in buildings. As a consequence the federal promotion programs "Energie 2000" and its still going on successor "Energie Schweiz", the Cantons, numerous energy intensive-firms, the energy agency of the Swiss economy (EnAW), the programme Climate Penny, and others were and still are much focussing on energy efficiency, increasingly taking advantage of the large and low cost potentials of energy efficiency in the buildings sector.

Cost effectiveness and techno-economic potentials of energy efficiency in the buildings sector have been the subject of quite some studies in various countries². One of the first having addressed the issue for Switzerland were the experts group Comprehensive Energy Conception GEK (cf. Ginsburg et al., 1975) and Brunner (1978). Cost effectiveness, potentials and possible benefits were addressed during the 1980ies by an experts group called EGES (Experts Group Energy Scenarios) and by Brunner et al. (1984), and more recently by Basler&Hofmann (1992) and the so-called "Energy-Perspectives" of the Swiss Federal Office of Energy (BFE, 1996). Most of these studies concluded that energy efficient new buildings and energy efficient renovations and retrofits of buildings are close to be profitable or even profitable from a private point of view, depending on cases and assumptions on discount rates, future energy prices, time perspective and reference behaviour (alternative investments, passivity). From a societal point of view the cost effectiveness of energy efficient buildings is even more significant due to usually lower discount rates and longer time scales that improve the economic effectiveness of the mostly capital intensive energy efficiency measures. From this point of view the buildings sectors, in particular the existing building stock, bear large and comparably cost effective potentials to reduce the countries' fossil fuel import dependence, to mitigate local air pollution and to curb the emission of greenhouse gases, i.e. to reduce external cost of energy use in Switzerland and elsewhere.

Obstacles

However, despite this apparently quite favourable situation it became evident since the end of the 1970s that private owners and investors hardly made use of the opportunities offered by energy efficient buildings and that energy efficiency potentials in the context of refurbishing houses and buildings remained untapped to a large extent. Partly this is due to several barriers or market failures that still exist and partly due to differences between the private and societal perspectives with longer time perspectives, lower discounting rates and overall welfare perspectives. With respect to the above-mentioned environmental goals, even some additional costs are justified from the public point of view. Indeed from a welfare economics point of view the discrepancy between a long term optimum and the actual behaviour of the private actors was even more evident. Although the availability of empirical data regarding energy relevant renovations was quite limited it could be concluded from the so called ex-post analysis of the Swiss Federal Office of Energy (BFE, 1996 - 2006) that energy efficiency improvement of the buildings sector was occurring only at a quite low rate and that potentials were still untapped to a large extent.

Apparently some relevant factors prevented the adoption of energy efficient solutions when constructing, renovating and managing buildings. The discrepancy between the presumed economic optima from a life cycle cost point of view and the observed behaviour of building owners and managers was (and still is) heavily debated in the research community, by policy makers and

² Germany: Feist (1986), Enquête Commission (2002); Great Britain: Harris (1982), DCLG (2006); France: Jestin-Fleury and Pinto (1988), EU: Eurima (2005)

stakeholders, both on the international and on the national level (IPCC, 2007). Whereas this discrepancy is discussed using the concept of market failures by classical economists, the reasoning of policy analysts also includes on the identification of barriers such as personal preferences, lack of information and transparency, high transaction cost, inadequate legal framework conditions that could explain the discrepancy which was called energy paradox or energy gap. This gap and the related barriers were already described in the 1980ies, for instance regarding consumer choices of household appliances (Anderson and Claxton, 1982).³ In the 1990ies major contributions were made by Jaffe and Stavins in particular for the building sector.⁴ For Switzerland the issue was addressed by Brunner et al. (1982). More recently, Marti et al. (1997), Econcept (2002) and Bättig (2005) identified the investor-user dilemma is one of the major barriers to comprehensive capital-intensive energy efficient renovations of rental apartment buildings which are quite relevant in Switzerland (about two thirds of the Swiss households are tenants).

Motivation to address the economics of energy efficiency in buildings

Energy services (i.e. well conditioned buildings for living and working) and useful energy demand (e.g. heat from radiators) bear some peculiarities as compared to other stages of energy use such as energy conversion and transmittance. One of the peculiarities is that energy relevant decisions or energy efficiency measures at the useful energy level often induce several impacts where more efficient energy use and related reduced energy costs and emissions are only one decision component and frequently it is not the most important one (Weber, 2002). Several impacts and benefits of energy efficiency investments in buildings make cost benefit analysis more challenging or even biased if not all aspects can be monetised or put into an appropriate economic appraisal framework.

The motivation of addressing the economics of energy efficiency in the buildings sector and to derive policy measures to improve the energy efficiency of this sector is mainly based on the observation of inefficiencies in the use of resources (including the environment) and of the presence of market failures which justifies policy intervention to correct these distortions. More specifically, the motivation is based on following arguments:

- Existence of (negative) external effects of current energy use, some of them with (very) long time horizons (e.g. climate change), that are not internalised in the present framework conditions.
- On the other hand, a more energy efficient energy use is characterised by (positive) external effects or co-benefits which are difficult to appraise,⁵ specially for private owners who are very relevant in the Swiss residential sector (almost all single family houses and three quarters of the MFH with two thirds of the multi-family dwellings are privately owned).

³ Many “barriers” are already part of the classical framework (preference based utility model of the consumer theory) or can be included in by refining the modeling or by theoretical extensions (transaction cost economics, information economics). Thus part of the debate was on a rather formal level, explaining the same phenomena by different approaches (it should be annotated however that policy conclusions may depend on the approach chosen). A debate is still going on between classical and behavioural economists.

⁴ E.g. Jaffe and Stavins (1994), see Jakob and Madlener (2003) for an overview of further contributions.

⁵ The frequency of energy-relevant decisions such as purchase and renovations is low and often unique. Thus information and search costs are high and the outcome of decision processes can often be used only once. Energy efficiency in buildings in many cases is a so-called experience good, i.e. relevant benefits can only be appraised after the decision is made (by living in such).

- Private and societal benefits are long-ahead due to the long life cycles of buildings and the renovation cycle (e.g. in case of increasing energy prices during the re-investment term of the building) and of climate change phenomena that often are not accounted for in private decisions and in policy making.
- Existence of information asymmetry and of transaction costs (cf. Ostertag 2003)
- Assumption of economic inefficiencies, a deficiency of innovation and cost reduction potentials of new efficiency technologies which often are more costly than traditional competing technologies.

External effects of the current high-level energy use in buildings include local air pollution, the use of non-renewable resources, climate change, and a high price risk exposure regarding imported fossil energies. Further external effects result from a forgo of opportunities and benefits which could be realised in the case of coherent energy efficiency policy (Jochem and Madlener, 200x).

1.2 The Problem

Starting point and motivation of the considerations made hereafter is the observation that there is a discrepancy between the private and the societal perspective in the presence of external effects,, and in the case of decisions with long-term impacts. Adequate framework conditions and judicious policy measures might be helpful to reach societal optimum. To design such policy portfolios effectively to improve energy efficiency in residential buildings in order to mitigate local air pollution, to curb the emission of greenhouse gases, to increase the security of supply and to reduce price risks resulting from energy import dependencies, it is important to have detailed information and a deep understanding on

- the technical and economic potentials of energy efficiency (EE) measures, which is indispensable to prioritise energy policy measures and shape economic instruments for this sector,
- the dynamics of the EE potentials and its economics, which is to adjust policy instruments over time, relevant due to the long-term cycles in the residential buildings sector
- the appraisal of EE measures by building users (residents), to take advantage of latent driving forces to promote EE, by strengthening these latent forces (e.g. demand for information on heating cost, demand for comfortable rooms and high indoor air quality by ventilation),
- the actual investment behaviour of the deciding stake holders, namely the building owners, architects, and installers and the behaviour-influencing factors, to adjust existing framework conditions, and to select appropriate and promisingly effective policy measures

The remainder of this section and of this PhD thesis are structured according to these main topics specified above. A separate chapter is dedicated to each of them, the first three of them being published in the scientific literature and the forth one being addressed in a CEPE-Working paper: Jakob (2006), Jakob and Madlener (2004), Banfi, Farsi, Filippini, Jakob (2006), and Jakob (2007).

Empirical estimation of the marginal costs of energy efficiency

Information on the cost-effectiveness of energy efficiency investments is useful for both private investors and building owners and for authorities and policy makers to define the economically efficient level of construction and renovation or to prioritize sectoral energy policy measures, i.e. to place energy efficiency measures in the residential building sector in the context of policy measures in other sectors and other fields (transport or industrial sector, electricity generation or appliances).

Indeed from a societal point of view the cost effectiveness is one of the most relevant criteria, next to other considerations such as the impact on labour, competitiveness, or innovation, the feasibility of policy implementation, and others.

Hence, due to the above mentioned discrepancy between the actual investment behaviour and the cost effectiveness claimed by different studies and promoters of energy efficiency the cost effectiveness as such was questioned by many stakeholders and policy makers. For this reason there has been (and there still is) a need for a sound and up to date analysis of the economic potentials and the economics of energy efficient investments in the residential building sector.

The cost-effectiveness of such investments can be expressed as the costs of conserved energy. In this PhD thesis it distinguished between marginal costs (MC) and average costs (AC) of energy efficiency (EE).

- The MC are defined as the first derivative of the building or renovation cost function reflecting increasing efforts of energy efficiency. In practice they are approximated by the ratio of the incremental costs and the respective incremental energy efficiency improvements.
- The average energy efficiency costs are defined as additional costs as referred to a reference point divided by the energy efficiency improvement. Average costs may also stem from several energy efficiency investments different marginal costs.

The advantage of the MC and AC approach lies in the fact the outcome can directly be compared with different energy price levels, influenced either by international markets (Switzerland is a price taker for most of the energy types) or by policy instruments such as energy and environmental taxes.

Energy efficiency investments often alter the state or the utility of the building elements in question, one of the utility elements being the energy efficiency. Indeed, such investments often are compound systems and yield several benefits, e.g. housing ventilation systems that provide both fresh air and EE, the latter in terms of heat recovery. As such buildings and construction measures are not a uniform product but rather differentiated by its attributes, similar to cars, consumer electronics, or production machines, and a whole variety of other products. Hence the challenge was to allocate the costs to the EE related benefits and to all other benefits respectively, i.e. to identify the costs due to EE improvements, everything else staying equal (*ceteris paribus* approach).

In determining the MC and AC empirically the challenge lies in the fact that the costs of building constructions or a renovations and the energy efficiency gains depend on a variety of influencing factors, both from the private perspective and even more from the macro-economic, societal and policy perspective. These factors include

- the (incremental) investment costs, i.e. construction, material and labour costs of the measures as such, depending on the technology and material chosen, and eventually on indirect cost effects such as heat generation and distribution cost reductions
- the (heating) energy efficiency gains obtained from the EE measures
- the actual (or assumed) lifetime of the measures and the assumed interest or discount rate

Both investment costs and energy efficiency gains depend to the reference case to which they are referred to. Likewise investment costs and EE gains depend on the aimed energy efficiency level; construction, material and labour costs usually increase and energy efficiency gains usually decrease with more enhanced energy efficiency levels.

Finally that the techno-economic approach estimating the marginal costs of EE yields some severe limitations in cases where not all benefits can be quantified by techno-economic methods. This applies typically to the so called co-benefits such as increased thermal comfort, improved air quality, enhanced noise protection, re-establishment of the new state of the building components, and others. In CHAPTER 1 (Jakob, 2006) the main focus is put on to the cases which can be handled by a judiciously defined reference cases to allocate costs appropriately to the energy efficiency gains. These are basically the cases where the investments include – next to energy efficiency gains – only the re-establishment of the new state of the building components.

Hence, information on the MC and AC of EE is an important, but not sufficient piece of information to design an effective and efficient energy policy. Indeed, to design effective and economically efficient policy instruments it is necessary take into account the total benefits of energy efficiency measures, i.e. also the so-called co-benefits of energy efficiency in the residential building sector. These kinds of benefits were addressed roughly in Jakob (2006), and more deeply and specifically in Chapter 4 (Banfi et al., 2006).

Dynamic viewpoint

Mid or long-term energy policy design may not be based on current cost benefit relations only. Indeed environmental, technical, economic and societal developments and structural changes might lead to changes that alter relevant decision criteria. An important example of such a development is the relative cost-effectiveness of innovative technologies that are being developed or already entering into the market place, as compared to established ones. This applies typically for environmental, renewable energy and energy efficiency technologies which were significantly more expensive as compared traditional conventional ones but could narrow the gap notably or close it even completely over a certain time period. Such a techno-economic development can be observed for all types of new technologies, products and services and it can be expected that it occurs likewise in the residential building sector in general and the case of energy efficiency technologies and measures in particular.

Insights regarding the potentials of the techno-economic development, its drivers and its susceptibility to be shaped are useful to support and justify such policy instruments. Such considerations – known as “financing the experience curve”, cf. Neij (1997), IEA (2000) – are heavily being made in the case of the development of renewable energies, but are much less common in the case of efficient energy end uses and related investments. To the author’s knowledge no scientific publication on experience curves in the residential or commercial building sector was previously available.

Hence one of the problems to be solved within this PhD thesis was to adapt and to apply the experience curve concept to the case of energy efficiency in residential buildings. This was realised in the authors’ research between 2001 and 2003 and reported in Jakob and Madlener (2004), cf. Chapter 2 of this PhD thesis. Several peculiarities of energy efficiency measures as compared to energy generating technologies were addressed, i.e. between demand reducing and producing technologies.⁶ These peculiarities in particular are:

- Marginal and average costs depend on a reference case (see previous section) which in turn is not static, but is also depending on a techno-economic development.

⁶ See table 2 in Jakob and Madlener (2004) for a comparison between electricity generation technologies vs. building envelope insulation measures/technologies

- The marginal costs of energy efficiency do not only depend on the stage of maturity of the technology concerned, but also largely on the efficiency standard actually chosen (insulation thickness, U-value, etc.).

The two mentioned issues are somehow interlinked and could lead apparently to outcomes that are not directly compatible with the basic assumptions of the experience curve concept, namely decreasing costs with increasing cumulative output⁷. This is due to the mostly strictly increasing character of the marginal cost function and the empirical observation at different points in time. Indeed, the marginal costs of energy efficiency could for example be observed at the low end of the marginal cost function at an early stage of innovation (at T0 in the schematic representation, cf. Figure 1) and at a more upper part at a later stage (at T1 or T2 in Figure 1). Since at T0 the cumulative output is low and higher at T1 and even higher at T2, the observed marginal costs as a function of the cumulative output are increasing in this example.

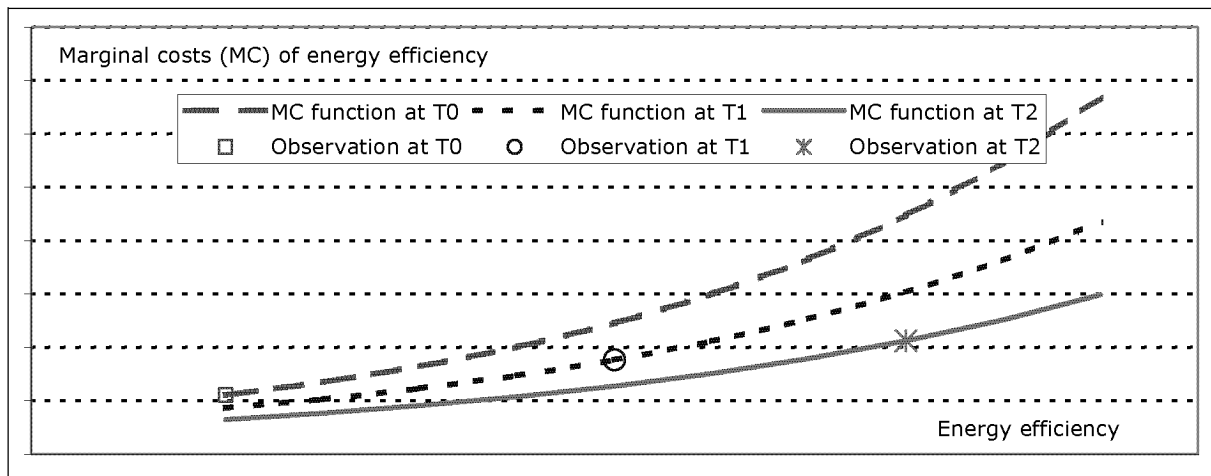


Figure 1 Marginal cost functions (lines) and empirical observations of mc (markers) at different time periods (schematic representation)

In other words the observed marginal costs of energy efficiency can be low at an early stage of innovation because the consumers prefer low insulation thickness, whereas later on, when the cumulative output has grown further (and consequently the experience curve concept would suggest lower specific costs), the MC of EE may in fact have risen because of an increase in insulation thickness used (e.g. due to legal requirements and/or higher energy prices).

Moreover energy efficiency investments concerning the building shell often consist of a combination of industrially fabricated products on the one hand, and the installation / application / mounting of these products on the construction site on the other hand. Depending on the relative cost share and the stage of the innovation process, different experience curve effects prevail (e.g. economies of mass production or learning effects, see Jakob and Madlener (2004), pp. 155 – 156 for an

⁷ This apparent contradiction to the usually well established relationship between costs and cumulative output could also occur in other empirical application of the EC concept where it is generally due to heterogeneity of the observed products (e.g. in the case of wind power if small and mature plants and large but newly developed plants are averaged instead of assessed separately).

overview on the different EC types) and the specific challenge was to evaluate how these effects could be integrated into a common approach.

Neglected benefit components (co-benefits)

The sector of residential buildings is particularly vulnerable to short-coming economic analysis frameworks, neglecting potentially relevant factors, mainly due to a lack of methodological know how and lacking missing empirical foundation. This specially applies for energy efficiency measures impacting directly on housing and comfort aspects, i.e. for building envelope measures, air renewal and heat delivery, but also for lighting. Energy efficiency measures in these fields might decrease or improve other utility components than EE. As a matter of fact energy efficient buildings provide high thermal comfort, constantly good indoor air quality, protection from external noise and burglary, and others. Neglecting these various impacts in investment decisions and their potential benefits in cost benefit analysis – for instance due to incomplete information about cost and benefits, in particular co-benefits – might lead⁸ to erroneous decisions both from a private and from a societal point of view.

A promotion of energy efficiency investments could be facilitated if more short term and more direct benefits could be appealed, since owners and tenants might respond to them more easily and more frequently, and also public acceptance of such a promotion would be increased. In the case of the buildings sector this approach is being successfully demonstrated by creating and promoting various trade marks that focus on energy efficiency and its co-benefits. Example are Passivehouse in Germany and Austria, Haute Performance Energétique (HPE) and Haute Qualité Environment (HQE) in France, Leeds in the US, and Minergie and Minergie-P in Switzerland. Their common denominator is that energy efficiency measures are primarily perceived as quality attributes that provide housing benefits rather than as a common (energy) investment item.

Information of the economic appraisal of co-benefits would ease such a promotion very much. A comprehensive economic appraisal of energy efficiency in the buildings sector is all the more important as buildings and most of its energy relevant components are quite capital intensive and have long technical and economic lifetimes. At the turn of the century it became apparent that not only general elements such as household equipment and indoor materials but also specific energy related attributes are of economic relevance, all the more so, as building appraisal is increasingly based on benefit providing and rent revenue relevant factors and on a forward-looking perspective.⁹ Martinaitis et al. (2004) pointed to the two-fold benefit of energy-efficient building renovation and suggested to include the building's elements condition into cost-benefit analysis (EE renovation would improve the building's condition or avoid building depreciation due to deterioration).

The literature of the discipline of housing economics suggests that building attributes have a significant impact on the economic value of buildings. Hedonic pricing models are one of the methods to reveal the marginal value of attributes and such models are commercially applied to estimate the implicit value (the implicit price, to be more exact) of buildings as a function of their attributes (cf. Wüest & Partner (2007), Cantonal Bank of Zurich, 2004; IAZI (2007) for Swiss applications).

⁸ Possibly combined with a lack of awareness, decision making based on the level of investment costs (instead of annualised costs) or on short-term (energy price) considerations, an exclusion of environmental aspects, and further socio-economic reasons (age, financial situation of the owners).

⁹ Rather than on a cost-oriented and backward-looking amortization perspective which traditionally has been more common. The professional part of the building sector is increasingly basing investment decisions and property appraisal more and more on future rental income which depends on the utility of the building using the discounted cash flow (DCV) method

Concluding from these applications one can expect that also energy efficiency attributes have an impact on the buildings' value. Neglecting or only including these utility elements in a qualitative way is a clear inadequacy since this might lead to non-optimal investment decisions. However, only little is known about how residents appreciate those energy efficiency attributes and even less is known about the economic value of the utility change of more energy efficient houses. However, despite the relevance of the issue there are only a few studies that addressed the building users' valuation of energy saving measures in buildings, cf. Banfi et al., (2006) for an overview.¹⁰

Hence, the challenge was to look for, to adapt or to develop methods and to provide evidence on the economic appraisal of energy efficient buildings and investments. It was to be taken into account that new elements such as housing ventilation systems as promoted by the label Minergie also were of interest. This implies either that the validity of results would be limited to market segments that experienced already these new elements (in the case of the market or revealed choice analysis) or that specific methods are to be used which are able to account for the hypothetical character of the elements. Both approaches were pursued in Ott, al. (2006), but a strong focus was lead on the latter, defining a suitable choice experiment. The econometric estimation of the tenants' and home purchasers' willingness to pay for energy efficiency attributes was conducted by Banfi, Farsi, Filippini, and Jakob (2006) and was accepted for publication in 2006 by Energy Economics, cf. CHAPTER 3.

Barriers and drivers of energy efficiency in the case of renovations

The deeper the issue of energy efficiency in buildings – in particular in the sector of existing residential buildings – is analysed, the more it gets evident that the scope of analysis is to be broadened to take into account the variety of factors influencing the individual decisions of all the involved actors. This follows from the findings of the broad literature on the cost-effectiveness of building EE measures and on barriers preventing a faster diffusion of energy efficiency (cf. Jakob and Madlener, 2003, for an overview). Hence the knowledge of the factors determining the owners' actual investment behaviour and a sound understanding of the prevailing barriers and drivers and of the market mechanism is an indispensable prerequisite to design effective and efficient policy measures. Private decisions and policy making that are based on incomplete or wrong assumptions bare the risk of being economically inefficient and might have only limited or even very little effect.

The issue is particularly virulent for the case of existing buildings, both in terms of quantitative relevance and in terms of availability of suitable policy instruments. Efficiency policies for existing buildings are faced with a particular problem, that desired and profitable efficiency investments by mandatory codes can only be implemented to a very limited extent, namely where major renovation is being undertaken anyway, but not for cases of light maintenance or passivity.¹¹

In Switzerland, for example, 45–60% of the façades from residential buildings erected prior to 1975 were renewed during the 15-years period 1986 to 2000, but most renewals comprised façade painting only (Jakob, Jochem, 2003). In each of these cases considerable energy efficiency potentials were not

¹⁰ On the one hand these studies point out that energy efficiency might be valued significantly by residents and that this valuation could be estimated with available economic methods. On the other hand, the evidence from the literature on specific values has been quite thin and could not have been transferred to the Swiss case.

¹¹ From a right to property point of view it is regarded as non feasible to force building owners to undertake large investments such as insulation measures. Also in the case of new buildings there is a discrepancy between actual construction modes and long-term optima. However quantitatively it is less relevant due to mandatory codes and standards and from a policy point of view the issue can be handled more easily, again thanks to codes and standards that can be re-enforced.

tapped. This observed renovation patterns can not be explained satisfactorily by costs and benefit relationships, at least if they are based on long-term consideration. Indeed results from Jakob (2006) and Banfi et al. (2006) suggest that energy efficiency renovations of facades, roofs and floors are economically viable if conducted instead of overhauling measures, even more if non-energy benefits are included, but all the more if they are valued economically as elicited. This applies to both privately owned and own-occupied single-family homes and for rented flats.

The empirically identified discrepancy between outcomes of project-based cost-benefit analysis and the observed decision patterns, also reported in other fields of energy use and in other countries, has been commonly ascribed to the existence of barriers leading to a so-called 'efficiency gap' or 'energy paradox' (cf. e.g. Jaffe and Stavins, 1994, Thompson, 1997, and others). Whereas there is more or less agreement in the research community on the existence of such a discrepancy, there is less unity regarding its causes and their theoretical interpretation. Sorrel et al. (2004) put the different discussion streamlines and views in a common framework outlining that a certain empirical observation has different names and meanings as viewed from the different perspectives. Following Sorrel et al. (2004, p. 51), the main approaches are:

- Presence of market failures. Some of the promoters of this approach deny the existence of a "problem", i.e. policy intervention would not be justified.
- Existence of "hidden" costs that are neglected by typical project based economic evaluation, such as information costs, and existence of other investment options (opportunism) (agency theory and economics of information)
- Bounded rationality and broader concept of transaction costs (transaction cost economics)
- All the above plus biases, errors, and decision heuristics (behavioural economics)

The bottom-line of the discussion certainly is that the investment behaviour does not depend only on the outcome of cost-benefit analysis but on several other factors.¹² Hence the challenge was to identify these factors for the case of the Swiss residential buildings sector. An analysis of the current renovation behaviour, the identification of barriers and drivers of energy efficiency in existing buildings was addressed with the research projects Jakob and Jochem (2003) and Ott et al. (2005) respectively. Jakob (2007) reports on the main evidence gained within these research projects and suggests a discrete choice model of revealed renovation decision, focussing exemplarily on the case of single-family home owners (CHAPTER 4).

1.3 Objectives

From the content point of view the overall objective of the research conducted in the framework of this PhD thesis was to fill the considerable gap of empirical evidence regarding a variety of elements that are essential for a comprehensive analysis of the economics of energy efficiency in the residential buildings sector and to derive a coherent set of policy measures to allot energy efficiency in residential

¹² Some analysts summarise the above "barriers" or market failures to only one factor, namely to an implicit discount rate. Empirically estimated rates are – as a result of the relevance of the barriers – quite high. It goes without saying that such implicit (and high) discount rates are suitable at the most for describing the actual investment behaviour but not as a parameter to be used in cost benefit (CB) or optimisation analysis. Such an approach misses explanatory power in view of policy design and runs the risk that policies subsidise already profitable efficiency investments.

buildings the appropriate standing in climate change and efficiency policy. These elements include the cost-benefit relationship of energy efficiency measures and its dynamics (changing cost per saved energy over time), both on the individual and aggregate level, and the understanding of the investment decision processes of building owners and its determinants. The focus of the analysis should be laid on the sector of residential buildings in Switzerland with a focus on energy services directly related to the building including heating and hot water requirements and use.¹³

On the one hand the outcomes should be general enough to be used in energy models and energy policy analysis (in particular energy demand projections of the Swiss Federal Office of Energy) and be useful for policy makers in federal and cantonal authorities and for intermediaries such as housing and professional associations. On the other hand the results should be specific enough to be useful for building owners, architects, planners, contractors and renovation companies to be applied in individual cases.

To face the multi-dimensional aspects, the inter-linkages and the complexity of the subject the objective from the point of view of content was structured into four main goals, namely

- to estimate the marginal and average costs of energy efficiency investments and their potentials at the current state, cf. the research report Jakob, Jochem et. al. (2002), and the publication Jakob (2006), Chapter 2 of this PhD thesis.
- to assess the dynamics of the costs of energy efficiency in buildings, cf. the research report Jakob, Jochem et. al. (2002) and the publication Jakob and Madlener (2004), Chapter 3
- to appraise of the total benefits from a building owner or user perspective, cf. the research report Ott et al. (2006) and the publication Banfi et al. (2006), Chapter 4
- to improve the understanding of the current renovation behaviour and to analyse barriers and drivers of energy efficiency in existing buildings, cf. the research report Ott, Jakob et al. (2005) and the working paper Jakob (2007), Chapter 5.

First, it was the goal to estimate the investment costs and the average and marginal costs of current and advanced energy efficiency measures, with a main focus on building envelope elements and housing ventilation systems. Gaps of empirical foundation, e.g. regarding the costs of energy efficiency measures and regarding energy relevant renovation rates, should be bridged with adequate surveys. Empirical findings should be interpreted regarding their context, e.g. regarding the current market situation, and adjusted to obtain generalized evidence. The results should be related to the legal requirements in the case of construction of new buildings, and to the re-investment cycle and the current overhauling and retrofit practice in the case of existing buildings. Specific, but frequent and decisive phenomena, e.g. resulting from the variety of the building stock or from building physics, should be covered and the result of decisive parameters on the results should be pointed out. The goal was to generate information on the level of individual buildings and on the aggregate level, i.e. to estimate a so-called energy conservation supply curve, to be used in bottom-up energy demand models. Moreover, results should be useful to design eventual promotion programs, i.e. to prioritize energy policy measures and to specify the need of eventual temporary subsidies.

¹³ Likewise relevant household appliances such as lighting, white ware, consumer electronics, etc. were not included. Further, the trade-offs between renovation of buildings and demolition-reconstruction is not addressed within this research thesis, mainly because it was already addressed quite comprehensively assessed by Ott et al. (200x).

Secondly the past dynamics of the costs and marginal costs should be formally described and empirically analysed. The goal was to verify whether energy efficiency measures in the building sector are also subject to economy of learning and economies of scale similar to those of conventional and new energy conversion technologies such as coal-fueled power plants, wind turbines and solar plants and to improve the understanding of its reasons and driving forces. Based on the results of these empirical and methodological findings the potential future techno-economic development should be projected, if possible for different market diffusion by policy scenarios. The above mentioned input for bottom-up energy demand models should be made available for mid and long-term time horizons.

Third it was to goal to appraise the total economic benefits of energy efficient building elements, buildings and renovation modes from a building user perspective, with a focus on elements that affect housing and comfort aspects, i.e. for building envelope measures such as thermal insulation and energy efficient window, and air renewal. Regarding the shaping of policy instruments it was to be considered that some of the co-benefits might be appraised differently by various residents or groups of residents such as allergic, noise sensible or environmentally conscious persons, smokers, age groups (elderly persons are often prefer warmer temperatures and are more sensitive to air drought) or income classes or in different circumstances, i.e. in different building contexts such as combination of elements, location and external situation. In view of a look-ahead perspective of policy measures new elements such as housing ventilation systems were of interest. Particularly it was the goal to examine whether the quality attributes promoted by the label Minergie were also of economic relevance, both in the sector of new residential buildings, a field of relative success of Minergie, and in the sector of existing buildings. Results should be useful for both the promotion of energy efficiency in various market segments in the building sector and possibly for system dynamics or hybrid energy models (cf. Jaccard and Dennis, 2006).

The forth goal was to improve the empirical basis of the actual renovation patterns in the Swiss residential sector and to deepen the understanding regarding the investment and renovation processes of the building owners. Having regard to long-term policy goals such as the climate change challenge or the 2000 W/cap society, the deficiencies regarding the energy related rate and quality of renovations and their causes should be analysed, taking into account both exogenous and endogenous explanatory factors. The terms exogenous and endogenous refer (i) to legal, organisational and economic framework conditions which can be – at least to a certain extent – influenced by policy measures and (ii) to social and internal factors such as owner type and age, motivations, building related goals and strategies, knowledge, and others, respectively. It should be distinguished between owners having realised energy efficiency renovation and owners who conducted only overhauling or renovations without energy relevance or did not realise any renovation.

The findings regarding marginal costs of energy efficiency and its dynamics, the economic valuation of the benefits of energy efficiency building attributes, and the decision behaviour and its determinants should then be put into their relative context. It should be pointed out how the findings can be used in policy design. Finally, policy recommendations should suggested on the basis of the new findings to more effectively promote energy efficiency in view of long term policy goals while increasing private benefits.

To reach each of the goals formulated above it was necessary to realise advances on several methodological issues. Hence from a methodological point of view it was the goal to develop a conceptual framework to decompose the variety of the current construction and renovation practice and the existing building park to generic elements to optimise between low survey costs and high

meaningfulness of the results regarding the marginal and average costs of energy efficiency, cf. Jakob, Jochem et. al. (2002) and Chapter 2 (Jakob, 2006). Up to date building physics methods should be included to improve the accuracy of the bottom-up estimates of marginal cost of advanced energy efficiency measures. Regarding the techno-economic progress it was to goal to develop a methodology to apply the experience curve concept to the peculiarities of building energy efficiency. It was the goal to formally adjust – for the first time – the experience curve concept to the case of energy efficiency, cf. Jakob, Jochem et. al. (2002) and Chapter 4 (Jakob and Madlener, 2004). To check out potential methodologies to appraise the of the total economic benefits of energy efficient buildings and renovations from a building user perspective, cf. Ott et al. (2006), and Chapter 3 (Banfi et al., 2006).

The methodology did not have to be built up completely from scratch. Some existing methodological approaches could be taken over from other fields of economics, but had to be adjusted to the specific needs and the peculiarities of energy efficiency in the buildings sector. Some of these adapted methods had been applied– to the author’s knowledge – for the first time – to the case of building energy efficiency. This applies in particular to the estimation of experience curves and their application to project the potential future development of marginal costs of EE in the context of policy design. Also the choice experiment approach was applied for the first time to housing energy efficiency attributes to be appraised by tenants (a similar approach was applied to homeowners by Sadler, 200x, but it should be noted that the incentive structure for this group is quite different since benefits occur directly to the investing agent).

1.4 Structure of the PhD thesis and author’s contributions

The PhD thesis is structured into four main topics, each of them representing a scientific publication. Three of them are either published or in press: the first one, entitled *Marginal costs, cost dynamics and co-benefits of energy efficiency investments in the residential buildings sector* is published in *Energy Policy* (Jakob, 2006); the second one, entitled *Riding Down the Experience Curve for Energy-Efficient Building Envelopes: The Swiss Case for 1970-2020* is published in the *International Journal of Energy Technology and Policy* (cf. Jakob and Madlener, 2004), and the third one, entitled *Willingness to Pay for Energy-Saving Measures in Residential Buildings* is in press in *Energy Economics* (Banfi, Farsi, Filippini, Jakob, 2006). The forth one Jakob (2007), entitled *The drivers of and the barriers to energy efficiency in renovation decisions of single-family home-owners* is available as *CEPE Working paper No 56* and will be submitted as publication.

The first topic comprehends the empirical estimation of the marginal costs (MC) of energy efficiency (EE) investments (i.e. additional insulation, improved window systems, ventilation and heating systems and architectural concepts) and its main influencing factors (Chapter 2). The MC of EE were estimated using a techno-economic approach which is often applied to provide input data for bottom-up models. The estimations included a survey of the unitary costs of the energy relevant building elements as a function of their technical energy characteristics. These cost elements were combined to hypothetical buildings of different energy efficiency, every thing else being equal. It was found that the building sector yields large energy efficiency potentials which are cost-effective or available at low costs, depending on assumptions about life-time, interest rates and future energy prices. The MC and the cost-effectiveness depends also on the energy efficiency level and on the company that provided the costs. The large variations in prices of newly developed technologies are discussed and interpreted as effects of pioneer market pricing, add-on of learning costs and risk components of the installers. The main outcomes of this research are published by Jakob (2006), based

on the research report (Jakob, Jochem, et al., 2002).¹⁴ The paper also includes first rough estimations on the order of magnitude of the economic value of co-benefits such as improved comfort of living, improved indoor air quality, better protection against external noise, an issue which is then addressed more comprehensively by Ott et al. (2006) and Banfi et al. (2006), cf. Chapter 4.

The second topic deals with the past and prospective dynamics of the costs of energy efficiency investments (Chapter 3). Based on new empirical data and evidence gained in the context of Jakob, Jochem et al. (2002), the past techno-economic progress and its drivers is analysed for the cases of wall insulations, glazing and windows. The cost dynamics of energy efficiency investments is formally described – for the first time - in the framework of the experience curve (EC) concept. The analysis addresses some of peculiarities of applying the experience curve concept to energy efficiency technologies. The potential of future cost reduction was estimated applying the EC concept and was published by Jakob and Madlener (2004). The author of this PhD-thesis contributed significantly to the conceptual set-up, adapted the experience curve concept from generation and end use technologies to energy efficiency applications in the building sector (insulation, glazing, windows). He conducted the empirical analyses including the survey of data from building technology companies and contributed significantly to the conclusions regarding implications for energy policy.

The third topic includes the estimation of total economic benefits of energy efficiency attributes of buildings from a building users' perspective and was addressed in the context of the research project Ott, Baur, and Jakob (2006). A choice experiment was used to evaluate the willingness to pay (WTP) of tenants and single-family house purchasers for these attributes (Chapter 4). It was found that the WTP is higher than the costs of implementing these attributes, if not by all so at least of a non-negligible proportion of the population. The findings regarding the econometric WTP estimations are published by Banfi et. al. (2006). The author of this PhD-thesis contributed significantly to the adaptation of the choice experiment method to the housing sector and to design of the choice experiment, in collaboration with colleagues from econcept (cf. Ott, Baur and Jakob, 2006). He also contributed to the model specification and econometric analysis, the interpretation of results, the conclusions regarding implications for energy policy measures, in collaboration with the co-authors of Banfi et al. (2006).¹⁵

The fourth topic deals with the existing building stock and the renovation behaviour of single-family home and multi-family building owners. Based on evidence and data gained from Ott, Jakob et al. (2005) and Jakob (2004) it addresses the low rates of energy efficient renovations which contrasts to the cost-effectiveness and the significant valuation of the benefits as estimated in the first topic and in the third topic. Chapter 5 of this PhD thesis is exemplarily focussed on single-family house-owners and analyses the barriers to and drivers of energy efficient renovations, on the one hand by analysing the technical, economic and legal boundary conditions and on the other hand by investigating the owners' perceptions of these boundary conditions as well as their motivations by means of surveys (cf. Jakob, 2007, planned for publication). Finally, Jakob (2007) suggests an econometric model of revealed renovation choices of SFH-owners. In the last chapter of this PhD thesis (Chapter 6) policy implications are derived from the outcomes of the four contributions and finally, suggestions regarding policy instruments to increase the EE in the residential building sector are being made.

¹⁴ The author of this PhD thesis collected the empirical data by written and personal interviews and designed the concept of alternative reference cases for the marginal and average cost curves for individual efficiency investments and types of residential buildings. The referent of this PhD-thesis contributed to the research report Jakob, Jochem et al. (2002).

¹⁵ One of the co-authors, namely Prof. Massimo Filippini, is the co-referent of this PhD-thesis.

CHAPTER 2

MARGINAL COSTS AND CO-BENEFITS OF ENERGY EFFICIENCY INVESTMENTS :THE CASE OF THE SWISS RESIDENTIAL SECTOR (JAKOB, 2006)

This Chapter 2 was published in *Energy Policy* 34 (2006) 172-187 and is referred to as (Jakob, 2006).

Abstract

Key elements of present investment decision-making regarding energy efficiency of new buildings and the refurbishment of existing buildings are the marginal costs of energy efficiency measures and incomplete knowledge of investors and architects about pricing, co-benefits and new technologies. This paper reports on a recently completed empirical study for the Swiss residential sector. It empirically quantifies the marginal costs of energy efficiency investments (i.e. additional insulation, improved window systems, ventilation and heating systems and architectural concepts). For the private sector, first results on the economic valuation of co-benefits such as improved comfort of living, improved indoor air quality, better protection against external noise, etc. may amount to the same order of magnitude as the energy-related benefits are given. The cost-benefit analysis includes newly developed technologies that show large variations in prices due to pioneer market pricing, addition of learning costs and risk components of the installers. Based on new empirical data on the present cost-situation and past techno-economic progress, the potential of future cost reduction was estimated applying the experience curve concept. The paper shows, for the first time, co-benefits and cost dynamics of energy efficiency investments, of which decision makers in the real estate sector, politics and administrations are scarcely aware.

2.1 Introduction and scope

In Switzerland – like in many other countries of the temperate zone – large and mostly untapped energy efficiency¹⁶ potentials lie, amongst others, in decreasing space heating requirements, which make up approx. 50% of the useful energy and approx. one-third of the final energy demand. Useful energy requirements for space heating of existing buildings could be reduced by approx. one-third to one-half compared to the present average value for the building stock and improvements by a factor of 5 or more can be achieved for new buildings (again compared to the average of the existing building stock) (see Ecofys, 2002; Avasoo, 1997; AWEL, 1998; Jakob et al., 2002; Binz et al., 2002; www.minergie.ch, 2003; SISH, 1997).

¹⁶ Energy efficiency measures, energy efficiency investments, energy conservation, etc. are used as synonyms.

In view of the objectives of the Swiss CO₂ law, which consists of reducing fossil fuel associated CO₂ emissions in 2010 by 15% compared to those of 1990, this energy efficiency and CO₂ reduction potential is of great significance. These potentials concerning buildings, in particular residential buildings, are not only significant because they are so extensive, but also because of the presumed low cost of tapping these potentials. However, at present many house owners and builders undertaking refurbishments barely take advantage of this potential. Partly this is due to numerous barriers that still exist and partly due to different objective functions between private and public economy. With respect to the above-mentioned environmental goals, some additional costs might be acceptable for the public economy. But from the private economy perspective, there might be a lack of profitability. This is especially the case if decision making is based on the level of investment costs (instead of annualised costs) or on short-term (energy price) considerations and if environmental aspects are excluded. In the market of rental flats (which is quite relevant in Switzerland), the investor-user-dilemma might be an obstacle for capital-intensive energy efficiency investments. Further reasons are incomplete information about cost and benefits, in particular co-benefits, lack of awareness and further socio-economic reasons (age, financial situation of the owners).

Indeed, building refurbishment with insulation¹⁷ was (and still is) often neglected by house owners. Only one quarter to one-third of the façade refurbishments carried out in the past 15 years included energy efficient refurbishment (Jakob et al., 2002). The remainder only received plaster repairs, or rather a new coat of paint. For roofs and windows, the share of energy efficient refurbishments is slightly greater. For windows, this is particularly the case. The last 15–25 years; window refurbishment mostly meant window replacement and due to great technological progress only noticeably improved windows were available. But overall there is still a very large potential for lowering energy requirements of the building stock, as the share of the construction components that are not yet improved with respect to energy efficiency is still between 30% and 80%, depending on the component (roofs, walls, windows, including cellar ceilings which are common in most of the single and multi-family houses in Switzerland in contrast to most of the EU countries). In addition, the building envelope is often not completely but only partly refurbished, as the inquiries and surveys carried out on building façade and roofing companies have shown. The energy requirements of refurbished buildings therefore generally do not decrease down to the low-energy consumption levels of new buildings. However, from a construction technology point of view, it is perfectly possible to reach this low level or even a lower level.¹⁸ This has been shown by a multitude of buildings of ‘MINERGIE’ label¹⁹ and ‘Passivhaus (passivehouse)’ standard²⁰ and P&D projects carried out in the

¹⁷ The terms ‘thermal insulation’ or ‘insulation’ include next to insulation of walls, roofs, etc. also more energy-efficient windows (coated, low-e).

¹⁸ Most construction elements (like walls, roofs, windows, cellar ceilings, etc.) of existing buildings can be refurbished to achieve a similar thermal quality as today’s new buildings, i.e. if insulation of 10–14 cm is added or the existing windows are replaced with such of glazing U-values of for instance 1.1W/m²K. Most heat loss of the thermal bridges can be removed at similar specific costs as area elements and only few thermal bridges might only be refurbished at high specific cost, but the energy loss of the latter could be compensated by applying more insulation to area elements. Indeed, an insulation thickness of 20 cm or even more does not cause any technical difficulty and the architectural challenge can be met in most of the cases. If the whole building envelop is refurbished, specific space heating demand can be reduced to less than 150 MJ/m²a, and to less than 150 MJ/m²a, if attention is also paid to air renewal heat loss.

¹⁹ Minergie (registered trademark) is a label of quality for new and retrofitted buildings that combines both the goals of living and working comfort and low demand of non renewable energy per square meter. There is a certain freedom of choice whether to meet the target value by improving the energy efficiency of the envelop or whether to use more renewable

last few years in Switzerland, Germany, Austria and other countries (see examples in Binz and Schneider, 2000; EMPA, 2003; ZEN, 2003).

Commonly given arguments for not fulfilling the complete energy efficiency potential are the energy paradox (Jaffe and Stavins, 1994), in particular inadequate tenancy laws (Metron, 1998), (temporary) budget constraints, insufficient knowledge of cost and benefits, etc. Often, investors, house owners or interest groups also refer to the poor economic profitability of energy efficiency measures, while on the other hand emphasis is laid on the extremely low-cost level of energy and environment-related improvements. Thus, an up to date, adequate and comprehensive economic assessment of energy efficiency measures with regard to the present and future costs and benefits of these options, as well as the shape of the marginal cost curve, form an important basis of information.

In addition to a differentiated updating of the present costs, the cost development of energy efficiency concerning building envelopes and heating systems is an important basis for long-term decision making. The future cost development is frequently an issue of new technologies, new materials and building concepts or processes. These partly include considerable learning potentials or potentials of serial production (economy of scale), which could, in future, reduce the costs of these new technologies and building concepts. So far, these cost dynamics have rarely been examined for the case of building envelopes. However, from a policy point of view, a comprehensive economic assessment should include this aspect of cost dynamics and how it can be influenced by policy instruments. Indeed, the literature reports on technological learning in many different fields and that policy instrument could make use of it by stimulating the learning and experience process to reach faster economic viability (see IEA, 2000; Neij, 1997). This paper takes up only very briefly, some results regarding technological learning in the field of energy efficiency of building envelopes. More details can be found in Jakob and Madlener (2004).

During the long-lifetime of thermal insulation investments in buildings, an increasing energy price level must be reckoned with in the coming decades due to an expected production maximum of mineral oil in many countries. This leads to a more accentuated concentration of the oil production the OPEC in general and to the Middle East in particular (see European Commission, 1999). Thus, due to political uncertainties and/or oligopolistic phenomena risks of higher energy prices should also be considered in the assessment of the benefits of thermal insulation investments. The assessment of such investments in residential buildings is not only concerned with an energy-related benefit, but also with other accompanying benefits. These so-called ancillary benefits or co-benefits include, for example, increased living comfort and operating ease, protection against external noise, additional safety, lower occurrences of respiratory illnesses, and improved leasing potential or betterment. These ancillary benefits and co-benefits are usually neither mentioned nor quantified. They are expressed in money terms in only few cases. However, they may benefit the real estate economy, as well as the tenants and builders and they may facilitate an appropriate and comprehensive economic assessment.

energy or heat pumps. Specific weights are associated to the different energy carriers to make them comparable. The target value for residential building for heating, hot water and electricity for heating purpose or air exchange is 150M/m²a (see Binz et al. (2002) and www.minergie.ch or www.minergie.com (in English) for more details).

²⁰ The German passivehouse standard limits the energy demand for heating to 15 kWh/m²a. More restrictions are made on the tightness of the building, primary energy consumption and the required capacity. See more details on certification conditions on www.passivhausinstitut.de.

Finally from a public economy point of view, the ancillary benefits arise as avoided external costs through reduced emissions. Although these external costs could reach the same order of magnitude as the today's energy prices they are not included in the analysis presented here. Firstly, to prevent overloading the paper and secondly, because internalising these costs seems not to be an option in the near future in real-world policies of many countries even though there might be exceptions. UK policy for instance, which is currently being revised, takes specific account of 'the social cost of carbon'. Currently, it is set at £70/tonne emitted for this purpose.

This paper reports on a recently completed empirical study for the Swiss residential sector (Jakob et al., 2002), the main objective of which was to improve the knowledge of the marginal costs of enhanced energy efficiency investments regarding the building envelope. The goal was to create a new and differentiated empirical basis, following a non-trivial approach and including new methodological aspects. This chapter is organised as follows: first, the methodological approaches of the empirical inquiries and the calculation of the marginal costs of the direct costs are outlined, and the energy-related benefits described (Section 2). A selection of results for the Swiss case is presented in Section 3. Then it is shown how an economic valuation of co-benefits can alter the results of cost benefits analysis, still from a business economic perspective (Section 4). In Section 5, the impact of cost dynamics on an aggregate marginal cost curve is discussed from an energy economics perspective. Summarising conclusions complete the paper (Section 6).

2.2 Costing methodology of the marginal cost concept

How much more does a greater insulation thickness or a more energy efficient window cost? How much energy efficiency can be gained and what further cost reductions can be reached through additional insulation? What is the cost of conserved energy? How do these costs compare to the conserved costs of energy (heat) generation? To answer these questions, we define the marginal cost of energy efficiency (mc_{EE} , Eq. (1)) and the average cost of energy efficiency (ac_{EE} , Eq. (2)). The two approaches can be characterised as follows:

- Marginal cost approach, defined as the first derivative of the cost as a function of energy conservation or for practical reasons; additional costs and benefits compared to the previously defined (discrete) efficiency step levels. The marginal cost approach is applicable for macro-economic considerations and for energy economy models, for the purpose of rational arrangement of promotion programs, for determining energy or CO₂-taxes, etc. For example, the additional costs of an insulation of 16 cm are compared to 12, 20 to 16, 24 to 20 cm, etc. are contrasted to the associated efficiency gain (reduced thermal transmission loss).
- Average cost approach, defined as additional costs and benefits compared to a reference case, see below. This approach is suitable if investment variants are compared to a reference investment, and it is used in practice, in particular, by house owners and the real estate economy (investors and administrations). All the different efficiency levels are hereby compared to the same reference, e.g. the insulation thickness 16 cm with 12 cm, 20 cm likewise with 12 cm, 30 cm likewise with 12 cm. Due to its 'marginal' character, as referred to a reference project, the average cost approach can also be termed as the 'project marginal cost'.

$$mc_{EE} = \frac{dCapCost}{dD_{Energy}} \cong \frac{\Delta CapCost}{\Delta D_{Energy}} = \frac{CapCost_n - CapCost_{n-1}}{D_{Energy,n} - D_{Energy,n-1}} = \frac{a_n \cdot IvcCost_n - a_{n-1} \cdot InvCost_{n-1}}{D_{Energy,n} - D_{Energy,n-1}} \quad (1)$$

$$ac_{EE} = \frac{a_n \cdot IvcCost_n - a_0 \cdot InvCost_0}{D_{Energy,n} - D_{Energy,0}} \quad (2)$$

where *CapCost* and *InvCost* denote the capital cost and the investment cost of the energy efficiency investment considered, a the annuity factor and D_{Energy} the energy demand of the buildings or of the construction element considered. The indices n , $n-1$ and 0 denote the energy demand levels considered, i.e. the various points on the marginal cost curve. The 0 indices refers to the reference cases which are defined as follows:

- *New buildings*: The present energy-related regulations with regard to space heating requirement of buildings (SIA 380/1, corresponding to EU-Standard SN EN832), or rather the actually realised energy-related quality of the new building which was empirically surveyed by (Brühlmann and Tochtermann, 2001).
- *Maintenance of existing buildings*: Maintenance activities on the building envelop, such as plaster renewal, painting of façade, roof maintenance, tile replacing, etc., could be used as an occasion to carry out efficiency measures. In these cases and with regard to energy, the reference case corresponds more or less with the energy-related quality of the original buildings (since the mentioned maintenance activities do not improve the energy-related quality of the building envelope), whereas cost reference is defined by the maintenance costs.
- *Energy efficiency refurbishment of existing buildings*: Each year a fraction of the building stock is not only maintained, but also improved in terms of energy efficiency. These energy effective refurbishments are the reference case for so-called ‘enhanced energy efficiency measures’ and the mc are of the type ‘What are the specific costs of conserved energy if, for instance, 20 cm of insulation is added instead of only 12 cm’. Both costs and energy relevant technical parameters of this reference case were empirically determined (e.g. façade insulation 12 cm, roof insulations: about 14 cm insulation thickness. Windows: U-value_{glazing}= 1.1 W/m²K; U-value_{wood frame}=1.4 W/m²K; U-value_{synthetic-frame}=1.6 W/m²K).

Expressed in kWh, the marginal energy efficiency (*MEE*) that can be gained through additional insulation can be approximately calculated from Eq. (3), where U_{ref} stands for U_{n-1} . HDD denotes the heating degree days. In the case of the average energy efficiency (*AEE*), Eq. (3) applies as it is (U_{ref} is not replaced by U_{n-1}).

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$$MEE(kWh) = (U_n - U_{ref}) \cdot 24 \cdot HDD \quad (3)$$

The resulting U-value due to additional insulation thickness Δd is related to the thermal conductivity λ (W/mK) and to U_{ref} , the reference U-value (U_{n-1} or U_0 of the existing construction), through

$$U_n = \frac{1}{\frac{1}{U_{ref}} + \frac{\Delta d}{\lambda}} \quad (4)$$

For transparent construction elements such as windows, the energy gain from solar heat (expressed through the energy gain coefficient, g -value) has to be taken into account. To calculate the gained energy efficiency for the building as a whole, adequate calculation routines are used to account for interrelation effects between heating losses and internal and external energy gains. For further details, see the norms SN EN 832 or SIA 380/1.

The following methodological approach was taken to empirically determine the mc of energy efficiency in the Swiss residential building sector:

- Inquiries concerning cost structure of façade and roof insulations with regard to insulation thickness, prices of glass and windows with regard to their U - and g -value, as well as ventilation systems with regard to their ventilation efficiency were made directly of companies. Particular interpretation problems of price statements of new technologies are discussed below.
- For individual components, the energy-related effect, i.e. the energy efficiency gain (=reduction of space heating requirements) was calculated using the U -value, see Eq. (3). Linear thermal transmission effects were included since they become more and more relevant when assessing highly efficient energy measures). The building as a whole was calculated using a physics of building model (complying with SIA 380/1 and SN EN 832).
- The annual costs were calculated by the annuity method, which makes considerations for the specific lifetime of the energy measures and for interest rates (see Table 1). For relatively long economic lifetimes, which are common in the case of construction type energy efficiency investments, the interest rate sensitivity of the annuity factor becomes more and more important as compared to the lifetime sensitivity.
- Individual investment measures were summarised into a cluster of measures, or rather investment packages based on the specific marginal costs and/or physics of building aspects, both on the level of individual buildings and of the building stock as a whole.

Table 1 Assumed economic lifetime and resulting annuity factor for different construction type energy efficiency measures at two different interest rates

Type	Economic lifetime (years)	Annuity at 3.5% interest rate	Annuity at 5% interest rate
Roof insulation	50	0.043	0.055
Wall insulation	40	0.047	0.058
Windows	30	0.054	0.065
Air renewal system	15	0.087	0.096

As most energy efficiency measures are matters of constructional investments with low maintenance costs the share of capital costs mostly lies at around 100% (with the exception of ventilation systems). Thus, the annual, or rather marginal costs are accordingly sensitive to the assumption of the real interest rate (see Table 1). From a macro-economic point of view, a real interest rate of 3–3.5% is regarded as appropriate and is used for the marginal cost approach. This interest rate might be suitable also for private building owners, but large institutional investors might apply higher interest rates. This is also the reason why the (project-orientated) costs were calculated using a real interest rate of 5%.

Finally, the marginal cost or average cost of energy efficiency can be compared to the marginal benefit of avoided space heating generation and distribution costs. The marginal benefit consists of

cost savings associated with smaller heating systems, but mainly of the reduced cost concerning energy purchase and it is thus highly dependent on current and future energy prices. There are two good reasons to believe that energy prices will increase during the long-lifetime of construction-orientated energy efficiency investments (Jochem and Jakob, 2002): (i) a rapid industrialisation and motorization of China, India and South America in the coming few decades, resulting in a large increase in the world-wide energy demand and coinciding with a decrease in production capacities for oil and natural gas in the non-OPEC states. (ii) The Swiss CO₂-law and the obligations of most industrial states according to the Kyoto protocol are possibly only the beginning of political reactions to climate change. Even a moderate CO₂-tax of 100 CHF/t CO₂ (66 Euro/t CO₂, exchange rate 2003) or an emissions certificate of about 70 \$/t CO₂ would cause an increase of roughly more than a half of the present oil and natural gas retail prices and would cause a prominent increase of heating costs (0.02 Euro/kWh for oil and 0.015 Euro/kWh for gas heating systems, assuming 0.9 efficiency).

In addition to the cost and benefit calculations described above, other elements must also be taken into consideration, if an integrated economic valuation is to be achieved: (i) the market environment of the cost surveys, (ii) technological progress and its induced cost dynamics, (iii) the economic valuation of the ancillary benefits of the construction-type investments and (iv) from a macro-economic point of view avoided external costs.

2.3 Marginal costs of energy efficiency – the building owners' perspective

For façade companies working on compact façades and ventilated façades, and for roofing companies, costs were inquired with regard to insulation thickness (see Figure 2 as example). Next to the insulation material as a function of the insulation thickness, also additional cost components, such as mechanical structures, labour costs, etc. were included. The insulation thickness was varied from the currently common insulation thickness in Switzerland (10–12 cm) up to 30–35 cm. Both the total costs and the cost structure were investigated. This showed that costs for insulation materials caused only around one-third to one-half of the additional costs as compared to the reference insulation. The remainder of the additional costs were associated with constructions, fixings (e.g. specialised plugs and screws, substructures), higher labour costs (more time consuming handling), and partly additional costs for scaffolding (consoles).

Contrary to expectations, the differences in cost curves between new buildings and refurbishments are small. Also the existing wall constructions have only a low influence on the investment costs. The costs for ventilated façades increase less steeply than for compact façades, as for the latter additional mechanical fixing becomes necessary from a certain insulation thickness onwards, while this fortification already exists for ventilated façades. If the construction details and connections between adjacent construction components are examined more closely, the insulation of the cill, jamb, and lintel or the roof edge may well cause additional costs during refurbishment, however, the additional energy-related effect results in marginal costs of conserved energy, which are rarely higher than the ones for area elements. Coordinated planning of the refurbishments is therefore worthwhile and recommended, even if the refurbishments occur at staggered intervals. Attention should be paid to the physics of buildings principles. If, for example, only the windows were replaced, the building could subsequently be too airtight, which would cause dampness problems on insufficiently insulated walls.

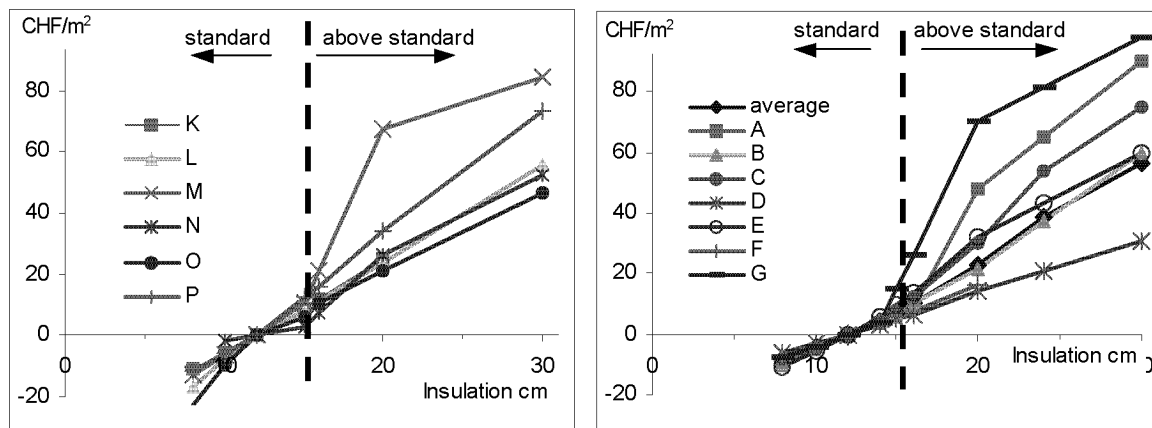


Figure 2 Additional investment costs for wall insulations for ventilated façade (left) and a compact façade (right) compared to the reference insulation thickness of 12 cm as a function of insulation thickness. Empirical data from different Swiss building companies (tagged A–P).

2.3.1 Economic interpretation of the surveyed cost data

The analyses also show that the cost curve for the currently common insulation thicknesses (8 cm up to approx. 16 cm) is about the same for all companies, which is in contrast to very large variations, which can be observed for greater insulation thickness (see Figure 2). Interestingly, the price gradient (as a function of insulation thickness) is – according to the surveyed companies – more or less the same for single-family houses as for multi-family houses. When interpreting the cost estimates of enhanced energy efficiency investments, it must be taken into account, that the appropriate market has only just started developing. The installing companies (or at least part of them) have no or only little experience of the technological aspects where the cost calculations are concerned. The variation in costs of such further-reaching measures is accordingly large. Moreover, the cost estimates may often represent learning costs or surcharges accounting for the “fear factor”, or the providers assume that the energy aware client thinks of himself as a pioneer and therefore accepts higher prices (pioneer market surcharges). Methodologically, these facts are taken into account by considering the best practice value in addition to the mean value, and by excluding those values identified as outliers when calculating the mean value.

The mentioned variation has a large influence on the marginal costs (see Table 2). For the reference case ER (energy efficiency refurbishment), the average costs of energy efficiency ac_{EE} of the company with the lowest (i.e. least steep) price increase (best practice) are much lower than the mean value and are therefore considerably closer to the economic viability, particularly for great insulation thicknesses. For the reference case M (maintenance), the ac_{EE} of best practice is 5% to almost 20% lower than the ac_{EE} of the companies mean and for reference case ER (energy efficiency refurbishment), the ac_{EE} of best practice is one-third to almost one-half lower than that of the mean. From an energy and climate policy point of view, it is therefore particularly effective to induce techno-economic progress through market stimulation. Given suitable expansion, learning and experience potentials can be activated and pioneer market surcharges can be avoided through greater competition, in order to adapt the costs, or rather the prices of all companies to best practice.

Table 2 Investments of façade insulations for refurbishments and average cost of energy efficiency for single and multi-family dwellings. (Mean value of the companies and best practice, real interest rate 3.5%) compared to the reference cases 'maintenance' or 'energy efficiency refurbishment'.

Insulation thickness (cm)	U-value (W/m ² K)	Investment costs (CHF/m ²)		Gross average costs (CHF/kWh _{UE})			
		Mean	Best practice	a _{CEE} , compared to Ref. ER		a _{CEE} , compared to Ref. M	
				Mean	Best practice	Mean	Best practice
0 (Ref. M)	0.85 - 1.1	35	35	N/A	N/A	-	
12 (Ref. ER)	0.28	117	112	-	-	0.061	0.058
16	0.23	127	119	0.12	0.08	0.065	0.061
20	0.20	140	133	0.17	0.10	0.070	0.067
30	0.15	174	143	0.25	0.13	0.084	0.069

Ref. M = Reference maintenance (plaster repairs, façade coating)
 Ref. ER= Reference energy efficiency refurbishment (12 cm external insulation)
 N/A = non-applicable

Figure 3 gives an overview of the results on average cost of energy efficiency (*a_{CEE}*) of different construction components, building periods and reference cases. Of each data series in Figure 3, the first data point from the left represents 12 cm (or 14 cm in the reference case of ER) and the following data points represent 14, 16, 20, 24 and 30 cm of insulation thickness, respectively.

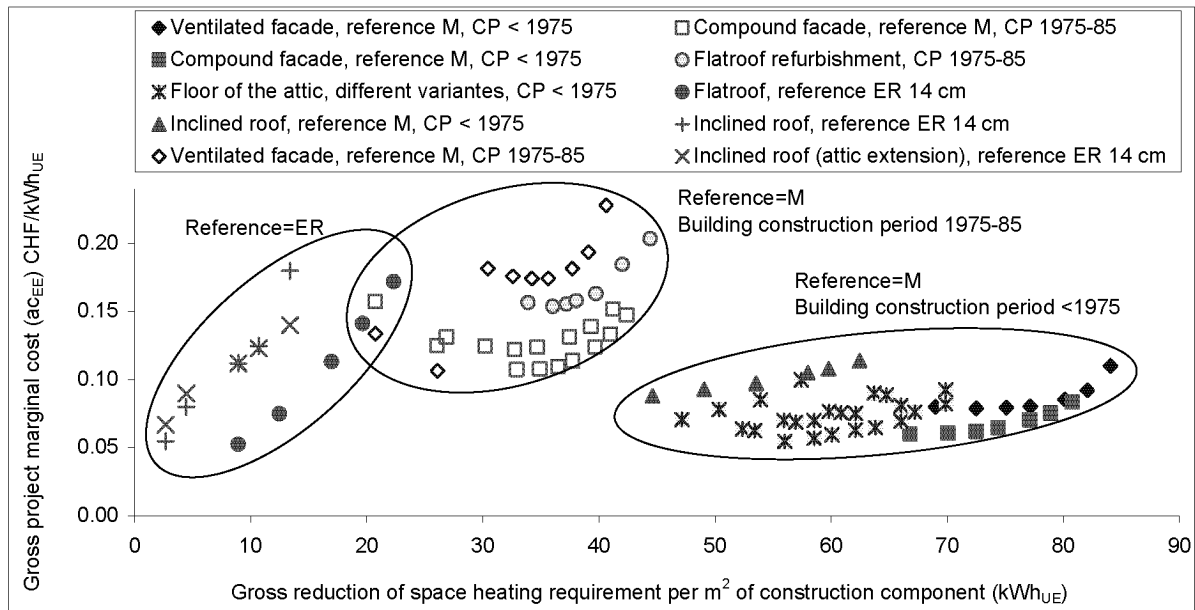


Figure 3 Summarising illustration of gross project marginal costs (*a_{CEE}*) for refurbishments (reference cases ER=energy efficiency refurbishment, M=maintenance only). CP: building construction period.

Three main insights can be inferred:

- For each of the reference cases of a certain construction period, it is apparent from Figure 3 that the average cost curve is approx. the same for most opaque, i.e. non-transparent, construction components. This means that at certain *a_{CEE}* (or project marginal costs) the efficiency gain per m² is approx. the same. The one exception is flat roofs, where the marginal costs are clearly lower. The implication of these findings is that from the cost point of view all (opaque) construction

components should be insulated to roughly the same insulation thickness. Because of architectural reasons one might insulate the roof more than the façade.

- The ac_{EE} for the reference M is higher for buildings of construction periods since 1975, since the construction elements are already insulated (even though only weakly). That means that the reference U-value is already lower (0.4 to 0.6 W/m²K) and as a consequence for roughly the same absolute investment cost per m² less energy efficiency can be gained, and thus the cost per kWh_{EE} is higher.
- For the reference case M (maintenance) the project marginal costs ac_{EE} are considerably lower compared to the reference case ER, especially for higher insulation thickness (low U-values). This can be understood by the fact that the efficiency gain per m² of refurbished construction component is considerably higher (e.g. 70 kWh_{UE}/m² for 12 cm compared to 0 cm and 80 kWh_{UE}/m² for 20 cm compared to 0 cm, while it is only between 7 and 9 kWh_{UE}/m² from 12–20 cm) as compared to the cost differences (see Figure 4 remembering Eqs. (1)–(3)).

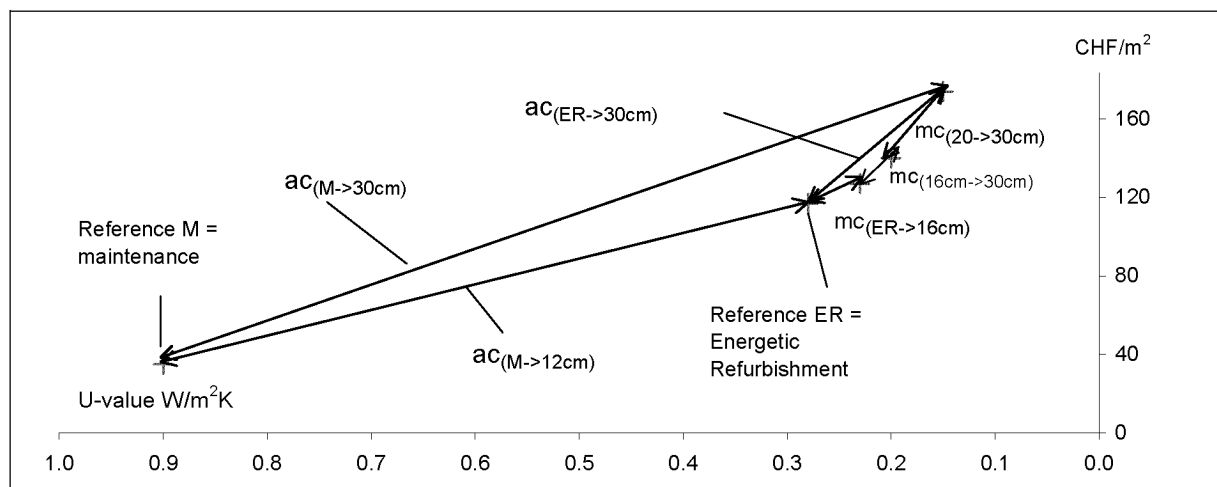


Figure 4 Cost of façade insulation as a function of the resulting façade U-value (stylised). The average cost of EE ac_{EE} for the reference cases M and ER and the marginal cost of EE mc_{EE} are proportional to the slopes of the arrows.

2.3.2 Windows and window frames

In the past, energy-related improvements of windows have been achieved particularly due to technological progress in glazing. But improved coating, different gas fillings and triple instead of double glazing can lower the currently reached standard of 1.1 W/m²K even further. The additional costs for this are similar for both wood- and 'plastic-' (e.g. PVC) framed windows. There are, however, big differences between small and large windows (see Figure 4). Large windows have lower reference U-values, which are due to the geometric conditions and the fact that the glass has lower U-values than the frame and lower specific costs per m². Furthermore, the price increase curve as a function of increased energy efficiency windows is less steep. A large highly efficient window meeting the stringent German passive house standard can be purchased at comparable specific cost per m² as a small standard window. The architectural element of designing larger windows is therefore particularly economically attractive in the case of new buildings even more if the reduced cost of the wall that can be omitted by the increased window is taken account.

In the last few years, attempts have also been made to improve window frames. For 'plastic'-framed windows, this development is further advanced than the one for wood or wood-metal framed windows. This is expressed by a wide market supply in the area of frame quality and is also apparent from Figure 5. The price increase of frame improvements is considerably greater for wood windows than for synthetic windows. However, the increasing demand for well-insulated windows due to the 'MINERGIE' label has also induced a supply market for wood windows, which meet the strict demands of the German passive house standard.

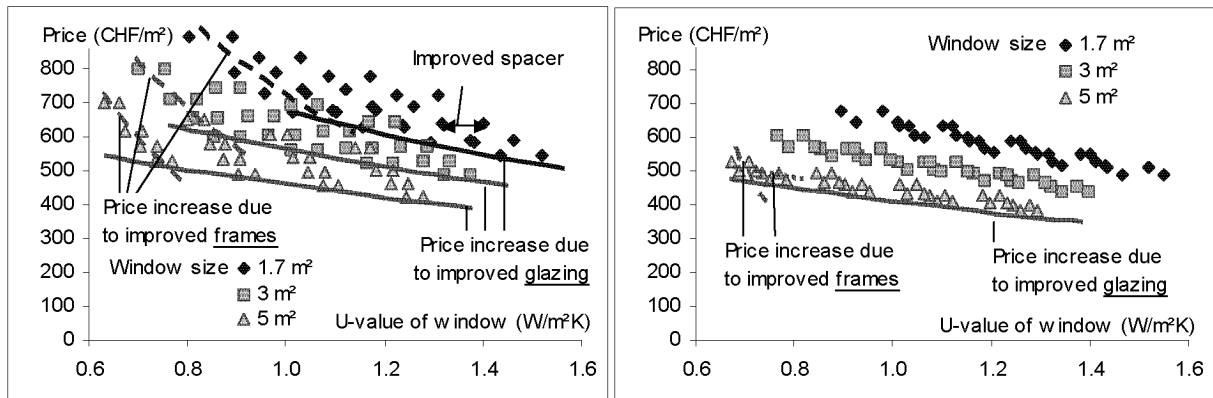


Figure 5 Investment costs for wood windows (left figure) and 'plastic' framed windows (right figure) for different window sizes in relation to the U-value of the window as a whole.

Energy efficient windows have to be assessed differently to non-transparent construction elements, as their energy balance depends on not only the reduction of transmission losses, but also on the solar gain of the different window and glass types. This implies that for a certain U-value, very different marginal costs can be obtained depending on the orientation, shading, the g-value, window geometry and the ratio of solar heat gain to transmission and air renewal losses in the building (Figure 6).

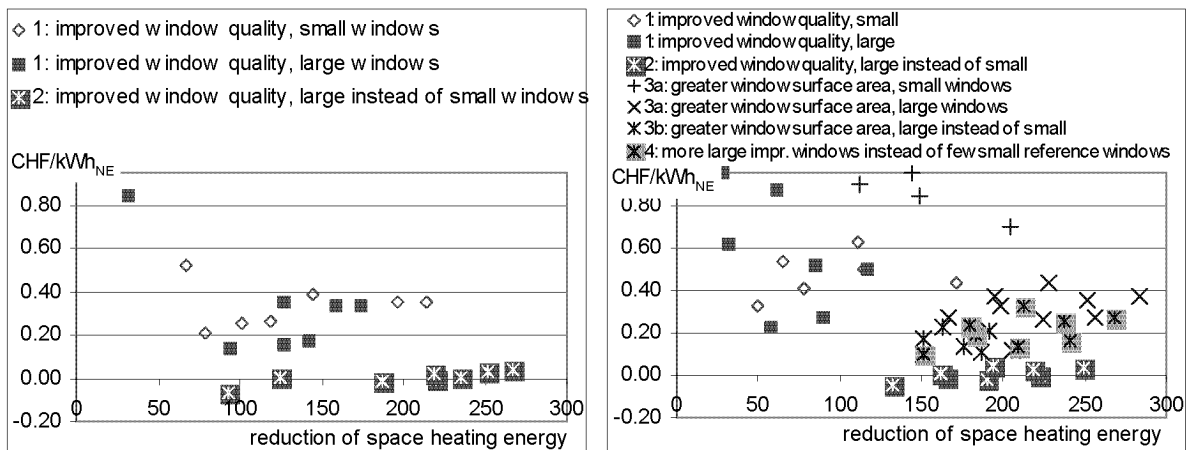


Figure 6 Summarising illustration of the gross average costs of more energy efficient windows of alternative architectural solutions (new buildings) for different cases and orientations (north: left figure, south: right figure), real interest rate 3.5%, 30 years lifetime. Source: Jakob et al. (2002).

For south-orientated windows, but also for slightly shaded east- and west-orientated windows, the energy flow is positive throughout the entire heating period. Here, the windows act as solar collectors and gain solar heat, which has a mitigating effect on space heat demand. Not only low U-values are

relevant for the choice of glass quality, but also the highest possible g-values (solar heat gain coefficient $\geq 50\%$, as otherwise U-value improvements are compensated by lower solar gains).

2.3.3 *The building as a whole*

For the step from individual construction components to the building as a whole it must be considered that the respective costs and the energy-related benefits of the different investment areas can partly influence each other. For this reason, the cost-benefit relation may be shifted from an isolated consideration to a consideration of the building as a whole. For example, the useful share of 'free' heat (solar heat gains plus heat from people and electrical appliances) deteriorates slightly with increasing insulation or increased solar gain and thus, the energy efficiency gained through insulation decreases and the specific marginal costs increase slightly. There are also interactions on the cost level: the costs for heat production and distribution can be reduced as space heating demand reduces.

For the existing building stock, the geometric proportions or the orientation of a building are given (and can be altered only to a limited extent). Accordingly, the potential for energy efficiency improvements can be derived from the individual construction components. However, for new buildings there is a certain scope to influence the energy requirements of a building by using architectural concepts. Such aspects may, for example, involve the avoidance of shading and the use of large windows. When constructing new buildings there is further leeway concerning the cover of the remaining heat requirements, because there is greater freedom of choice for housing technology than for the building stock, where there are additional boundary conditions (e.g. limited space, existing space heat distribution, which could for instance cause low efficiency for heat pumps).

The examination of different concepts for new buildings and different starting positions has shown that the marginal cost curve takes a relatively similar course. In Figure 7, a selection of three parameter variations is reported (more cases can be found in Jakob et al., 2002). Most of the individual measures show similar marginal costs and energy efficiency gains for the different building cases considered. The most noticeable differences can be observed when the share (not reported here) and the quality of transparent construction components vary for different shading cases and for the air exchange-related measure. If the air exchange rate is already low in the reference case (due to sealed construction and due to appropriate user behaviour) the possible gain in reduced heating demand of a mechanical air renewal system is lower and thus the marginal cost higher. This causes differences in the overall appearance of the marginal cost curves. Low specific space heating demand ($\text{MJ}/\text{m}^2_{\text{AREA}}$) in the reference case (low air exchange rate, low shading, low ratio 'envelope area' to RFA allows less reduction of the energy heating demand (applying the same measures) and thus, the marginal cost curve 'appears' steeper. In other words: for a given mc, less energy can be conserved. In some cases, the merit order of the efficiency measures may also change. It is, however, more essential that successive measures are taken for all construction components, as opposed to applying advanced measures selective to only some of the components.

In the form displayed in Figure 7, the gross marginal costs enable a comparison amongst the individual investment options, as well as a comparison of different concepts for new construction, but do not yet enable a final assessment of the economy with the inclusion of heat availability. The calculation of the system size takes place via the capacity requirement, while this, in turn, is calculated in a differentiated manner based on the actually considered building concepts. The capacity requirement usually decreases less than-proportionally to the reduction of the annual heating energy demand, because the coldest day in the absence of solar gains is authoritative to the dimensioning of

performance, while the heating energy requirements can be reduced by solar gains. With the possible use of small systems associated obtainable cost reductions are rather low for oil, gas and wood heating. For heat pumps – in particular for the ground source heat pump – investment costs are reduced more noticeably.

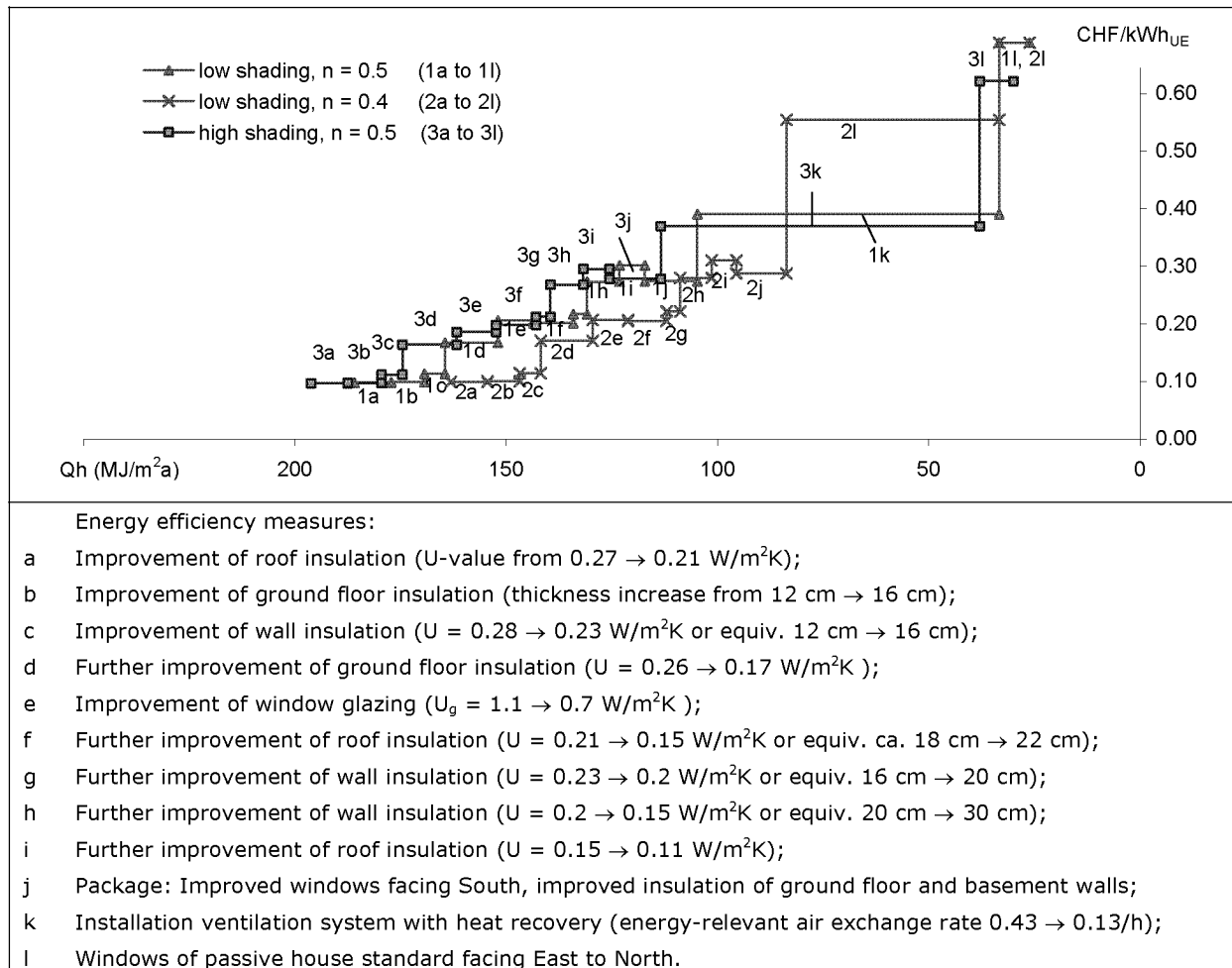


Figure 7 Gross marginal costs for multiple-family houses (without consideration of cost reduction on the part of heat production and distribution). Parameter variation for different starting conditions of shading and of air exchange. Source: Jakob et al. (2002).

At the current costs, the additional costs for thermal insulation investments cannot be entirely compensated for any system type, even if the hydraulic heat distribution of a well-built passive house can be omitted.

The costs and benefits can also be shown as annual costs with regard to space heating requirements Q_h , measured in MJ/m²a (see for example Figure 8). This illustration method facilitates a comparison with other cost components of the housing economy, in particular with rent prices.

The total annual costs are defined as the sum of the annualised capital costs (using the annuity method) of the energy efficiency investments plus yearly expenditures for heating energy requirements. The total annual (net) costs show – without consideration of ancillary benefits – an initially very flat curve in or below the area of current construction methods (e.g. between 250 and 200 MJ/m²a) (see Figure 7). In the illustrated example, an improvement of the specific space heat demand

Q_h of around 40–60 MJ/m²a (or by approx. one quarter) can be achieved without great additional costs, even when the improbable assumption is made that the average energy price throughout the entire lifetime is only 0.055 CHF/kWh (approx. 55 CHF/100 l). Space heat demands can be reduced by a total of over 100 MJ/m²a at net costs of 2–3 CHF/m², which would mean 20–30 CHF of additional costs per month for a flat of 120m². If an energy price increase in the area of CO₂-tax is estimated at 210 CHF/t CO₂, the cost curve becomes even flatter and the economic optimum is moved further to the left to a lower specific energy requirement.

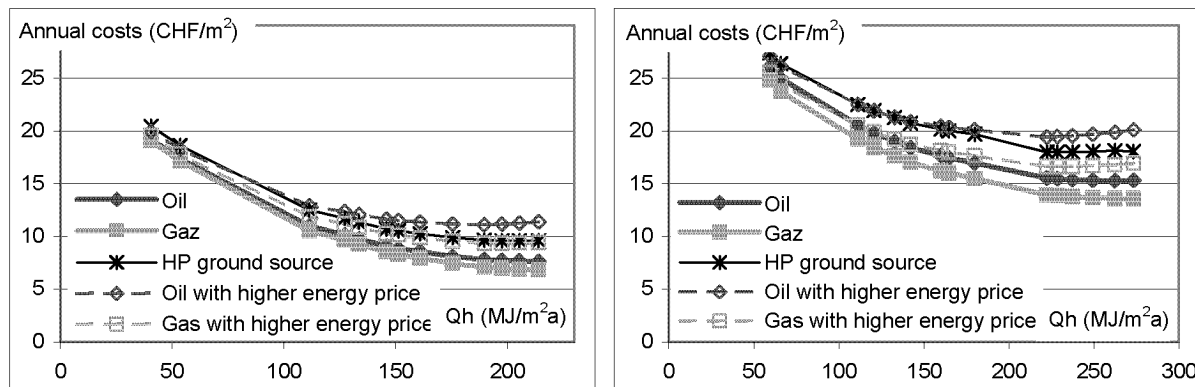


Figure 8 Annual costs (with consideration of cost reduction on the part of heat production and distribution) for different system types for multiple family houses (left figure) and for single-family houses (right figure). Higher energy prices for oil or gas heating: surcharges of 210 CHF/t CO₂. Source: Jakob et al. (2002).

The values in Figure 8 were not based on best practice costs (in connection with this also note the variation in additional costs in Figure 3 or Table 2); in future the cost increase could very possibly be more moderate than illustrated here due to growing learning and economy of scale effects. Also the non-energy related benefits, which can often be observed for further reaching energy efficiency measures (see below), have not been considered so far. In this respect, the above-described business economic net costs are incomplete and can lead to misjudgements where thermal insulation and energy efficiency investments are concerned.

In contrast to the annual costs curve which is very flat around the economic optimum (Figure 8), see also (Hinz and Feldmann, 2001) the investment costs (e.g. Figure 2) begin to increase immediately after the reference point, if only marginally. Decisions based only on the investment costs will therefore not result in a construction method which is optimal with respect to energy efficiency and economic efficiency. As trivial and as not particularly new as this finding is, it is often not given much attention in reality. In many cases, this is due to the investor/user dilemma and tenancy legislation, which is insufficiently aware of these connections.

2.4 Ancillary benefits (co-benefits) of thermal insulation investments

In addition to the above-described direct and indirect economic effects of energy efficiency measures, a comprehensive economic assessment has to include ancillary benefits and co-benefits. One can distinguish private and public co-benefits. In this section, the private ones are presented. In

the following, some examples are used to illustrate how the inclusion of such benefits into the business economic assessment can reduce the net marginal costs (see Figure 8):

- For the quantification of the increase in living comfort, empirical investigations on the thermal comfort were used which were based on differences between wall temperature and air temperature, as well as current conditions in the living space. It has been found previously (Fanger, 1970 and others) that a reduction of the temperature difference between the wall of a room and its average air temperature by around 5 °C enables a decrease in the room temperature by 1 °C without affecting the comfort level. The consideration of this effect, however, only leads to relatively small ancillary benefits of at best, a few cents of CHF per kWh of conserved heating energy.
- Replacement of old double-glazed windows, the installation of double or triple-glazing with asymmetrical glass construction and special glass types, the renewal of roller blind casings as well as (heavy) insulation material made from mineral substances, all help to reduce the transmission of external noise into the interior of residential buildings. A quantification of the noise reduction can be obtained by estimating the reduction of the noise-associated costs. These noise costs were empirically observed, amongst others, as rent losses as a function of noise pollution and have been given as 0.6–0.9% per each additional dB by different studies (e.g. Ecoplan, 2000). As a rough estimation, we estimate that these economic losses are reduced by 50% if a new window replaces an old window without rubber seal. Also insulation measures using mineral materials in roofs are of relevant significance (in particular against air-traffic noise or traffic noise transmitted over large distances). Old windows reduce the level of external noise in the interior of the building by about 20–25 dB, whereas new ones achieve 33–35 dB. Even 38–40 dB are possible if (asymmetric) triple glazing is applied. Hence triple glazing offers further energy efficiency potential. Thus at noisy locations, an improvement of 10–15 dB could result in gross economic benefits (of reduced economic losses) up to the amount of 3–7% of the rental income.
- An economic analysis which was conducted recently by the Zurich Cantonal Bank (Zürcher Kantonalbank) using the hedonic pricing approach shows a valuation of energy efficient windows of 2–3.5% of the selling price of existing single-family houses (Borsani and Salvi, 2003). The same analysis reveals that new single-family houses certified with the ‘Minergie’ Label yield higher selling prices by almost 9% (with a standard error of about 5%).
- The selected examples show that for windows and roofs protection against external noise can significantly influence the profitability of heat insulation measures. Indeed direct net costs (annualised investments minus reduced energy cost) are in many cases below the mentioned benefits: Net direct cost of 2–4 CHF/m²a (see Figure 8) represent 1–4% at typical rents of 100–200 CHF per square meter and per year. And net direct cost of 2–4 CHF/m²a represent capitalised costs of about 8’000–16’000 CHF (capitalization factor 5%, i.e. 3.5% real interest rate, 35 years of economic lifetime) represent 1–2% at typical selling prices of single-family houses of 500’000 to more than 900’000 CHF. The total direct net costs of ‘Minergie’ buildings amount to about 7–10 CHF/m²a (equivalent to 3–7% at capitalized level) at today’s energy prices and to 3–5 CHF/m²a (1–3%) if a CO₂-tax of 210 CHF/tCO₂ were applied.
- Through improvement of indoor air quality, the use of ventilation systems has a similarly large influence on the comfort of living. On the one hand, either better air quality in flats of residential buildings located in strongly affected neighbourhoods (e.g. near busy roads) are reached by a

reduced air exchange rate for windows and doors replacements or by filtering the outside air through ventilation systems and/or by drawing in air from the part of the building turned away from the road. The opposite case is a too-low air exchange rate in well insulated and sealed residential buildings which have excessive interior humidity (e.g. due to plants, cooking, showering while not ventilating enough) or which have a relatively high pollutant concentration caused by the inhabitants (excessive smoking) or by the interior furnishing (e.g. synthetic carpets, furniture with pollutant emissions). These pollutants are intolerable to asthmatics and other people with a disposition for allergies and respiratory illnesses. The quantification of these effects, however, is generally very difficult. Expressing these effects in financial terms has to be attempted using epidemiological analyses for the respective diseases, econometric methods on revealed preferences (rental or selling prices) or empirical studies on stated preferences (direct or indirect willingness to pay). First results of a current empirical study indicate a willingness to pay for so-called comfort air renewal systems of 5% of the rental fee of apartments in new buildings (Ott et al., 2006). If this kind of benefit is deducted from the cost of the air renewal system, only the remaining part needs to be attributed to the gained energy efficiency. In doing so, the marginal cost of energy efficiency drops dramatically as indicated by the arrow in Figure 9. As a consequence, the merit order of the measures could change.

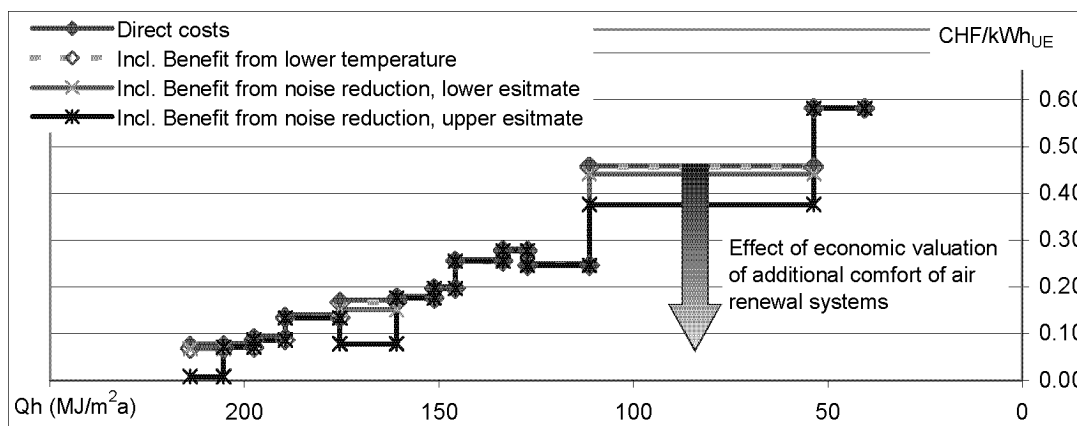


Figure 9 Marginal cost curve for insulation investments with consideration of selected co-benefits (greater comfort, protection against external noise, better room air quality due to ventilation systems), case study with oil heating. *Source:* Jakob et al. (2002).

2.5 Marginal cost curves – the energy economics perspective

The energy economics perspective differs from the business economics one, on having different optimisation goals. From a public economy and welfare point of view, optimal energy efficiency level is obtained if the marginal cost of different options (to reach a certain goal) are equal. It is important to notice that marginal costs (and not average costs) should be compared. For national goals, nationwide marginal cost curves are a suitable instrument to determine reduction potentials (of say energy demand) for a certain energy price or to determine the level of a CO₂-levy to reach a certain reduction goal. A nationwide marginal cost curve allows for an appropriate accounting of all potential measures. Knowing about the dynamics of the marginal cost curves and knowing how these dynamics can be influenced by policy instruments are other elements that distinguish the business and the energy economics perspective. The focus of this section is put on the marginal cost curve at

present costs and also the dynamics of it is touched only very briefly, see Jakob and Madlener (2004) for more insights.

To construct a marginal cost curve, first the reference for the type of new construction and the reference for refurbishment conduct is defined for typical cases and with regard to thermal and construction technology characteristics on the level of construction components, or rather buildings. Subsequent to this qualitative dimension, the quantitative relevance, i.e. the nationwide frequency of these cases was determined. In order to do so, existing publications and statistics were used, and primary inquiries were carried out (see Jakob and Jochem, 2003) since statistical data with respect to energy-related refurbishments are not available in Switzerland.

For a marginal cost curve, the definition of a reference development forms an indispensable basis, as all additional investments and their associated energy savings are based on this reference. When considering the whole of Switzerland, the definition of a quantitative model for future activities concerning new buildings and refurbishments becomes necessary in addition to the construction technology characterisation. For new buildings, this is relatively easy; here knowledge of the future dwelling area of new buildings and the existing construction methods of the individual construction components are sufficient (see previous chapter). With regard to the future heated space floor area (also referred to as energy reference floor area, RFA) for new buildings the views of Wüest and Partner (1994) can be drawn upon. For example, by 2010, an area of around 27 million m² is expected for single-family houses and an area of 25 million m² for multiple family houses.

The investigation carried out by (Brühlmann and Tochtermann, 2001) reports energy consumption values specifically new buildings to be around 400 MJ/m²a (includes warm water requirements and conversion losses); this indicates that in practice the abovementioned 12-14 cm are not entirely reached. Moreover, the reference case cannot be represented by a single value, as the space heating requirements have a relatively large variation. This is in contrast to the simplified approach adopted in the present analysis. However, this approximation does not significantly affect the results. The trend for more advanced thermal insulation, which first began in the area of new buildings, was also transferred to building refurbishments, but only in those cases in which the energy aspect was of any significance to the investor. For energy related refurbishments, the insulation thickness and the applied window qualities are generally similar to those used for new buildings. In particular circumstances, one's sights have to admittedly be lowered due to construction technology conditions and construction process. For example, no or only low insulation may be justified for those construction components adjacent to the connections, such as around windows and doors, edges of flat roofs or transitions between walls, roofs and the ground.

For the reference case, the usable energy demands of buildings newly constructed by 2010 is around 7600 TJ. For the whole of Switzerland heating requirements (on the level of useful energy) can be reduced by 1300 TJ for new single-family houses at gross marginal costs of 0.10 CHF/kWh_{UE} if measures for floors, roofs, walls and windows are taken. For marginal costs of up to 0.20 CHF/kWh_{UE} this could be reduced by a further 935 TJ. These marginal costs are considerably lower (almost a factor of two) if best practice is applied. A comparatively large savings potential of 1300 TJ of space heat demands theoretically, enables the installation of ventilation systems (if ventilation systems were installed in all multiple family houses). However, the realisable portion is estimated at only 30%. The marginal costs are between 0.23 and 0.38 CHF/kWh_{UE} depending on the situation and the heat production, if the entire costs for the ventilation system are allocated to the energy efficiency. These marginal costs must be compared to the respective heat cost (long-term mean energy price divided by

the efficiency of the systems). The heat cost is between 0.05 CHF/kWh (present fuel prices) and around 0.10 CHF/kWh (increased international fuel prices and/or CO₂-tax, or rather emissions certificates). Depending on the assumption (average construction cost or best practice, today's energy price or increased fuel prices) a more or less significant efficiency potential can be tapped at 0 or low net cost (still excluding private co-benefits). For multiple family houses the annual space heat demand of the 25 million m² of new buildings the RFA is around 5600 TJ for the reference case. The space heat demands could be reduced by around 700 TJ, if energy efficiency investments were made for gross marginal costs of up to 0.10 CHF/kWh.

Describing the reference development in the area of building refurbishments is somewhat more complex. Next to the knowledge of the initial condition of the construction technology for the different building categories (type, construction period), additional assumptions about the rate and type of refurbishment are needed. What is the quantity of construction components (walls, roof, windows, cellar ceiling, etc. and their respective combinations) that is renewed and how much energy reference area would be affected? What is the share of maintenance (such as wall painting that is not energy effective) and what is the share of energy efficient refurbishment? The empirical basis of refurbishments with regard to thermal insulation in the past and which could serve as a foundation for describing the development of future costs is relatively weak in Switzerland (and in most countries). As a consequence a survey aimed at filling this gap was initiated (Jakob and Jochem, 2003), but as results from this project had not been analysed before the completion of the calculations of this chapter. Therefore, provisional assumptions had to be partly made for the reference development in the refurbishment sector. Despite this reservation, the Swiss nation-wide marginal cost curves for the refurbishment of residential buildings is very informative. This is owing to the fact that a large energy efficiency potential was established at relatively low cost, particularly if a comprehensive economic assessment is applied.

This is demonstrated for single-family houses from the construction period between 1900 and 1961. In the reference case, the reduction of space heat demand is 7% by the year 2010 for buildings of this construction period, as next to maintenance there is good reason to additionally expect energy-related refurbishments, as it could have been observed for the last 10–15 years. With regard to the marginal cost curve, it is assumed that within the next 10 years, an additional 15% of the total of a building's walls are insulated and that the insulation thickness will be 20 cm instead of 12 cm (see Figure 9). For the roof it is assumed that in the reference case 1.5 millionm² (6.5%) will be refurbished with thermal insulation of 12 cm and that for the marginal cost curve insulation thickness should be increased from 14 to 20 cm. Moreover, it is assumed that for an additional 1.9 millionm² (8.3%) not only tiling and/or underfelt are renewed, but also that insulation is installed (Figure 10).

A considerable potential for reducing space heat requirements of approx. 1100 TJ lies in the range of gross²¹ marginal costs with up to 11 CHF/kWh_{UE}. At this cost and in addition to the reference development heat requirements could be reduced by a further 9% (compared to the entire building stock of single-family houses of the construction period from 1900 to 1960). With gross marginal costs between 0.09 and up to 0.13 CHF/kWh_{UE} heat requirements could be reduced by a further 3%. From these costs, the saved costs from heat generation and distribution must be deducted. In the long-term, these cost savings amount to 0.01–0.03 CHF/ kWh for the heating systems and 0.04–0.06 CHF/kWh for

²¹ Gross marginal costs: (annualized) capital costs prior accounting for marginal benefit of reduced heat generation (cost of saved energy plus reduced capital and O&M costs for heating systems).

the energy costs based on energy retail prices of past years and 0.08-0.11 CHF/kWh based on future prices.²² The respective reduction potential of ongoing measures subsequently decreases and the marginal costs begin to increase significantly (see Figure 10).

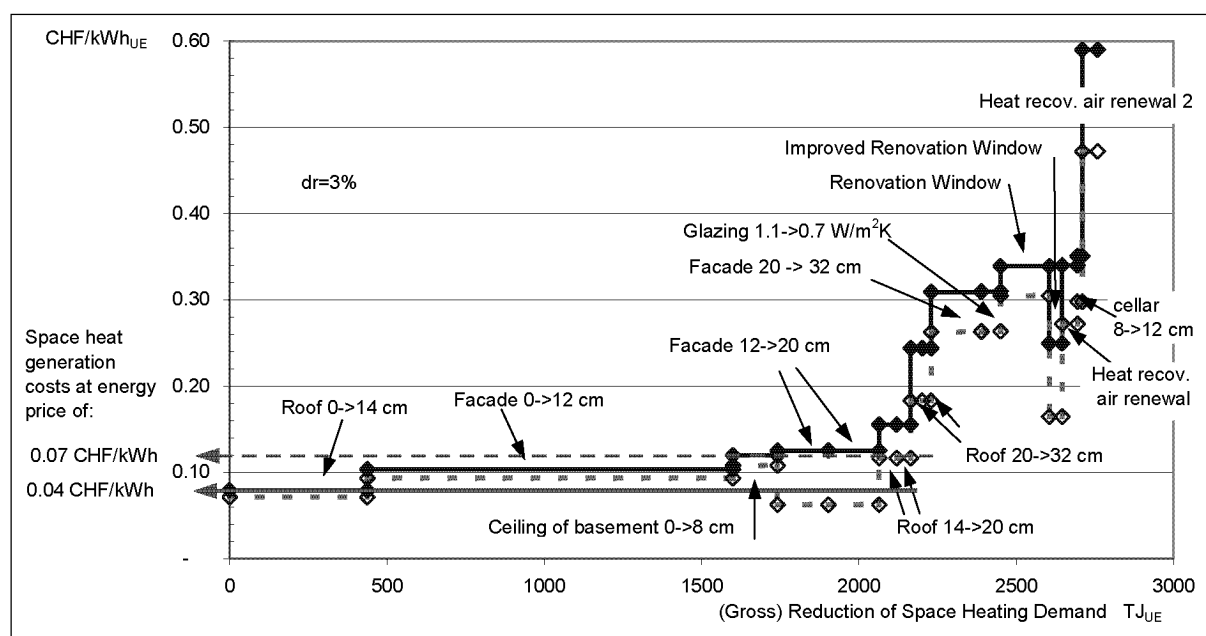


Figure 10 Marginal cost curve of the single-family house building stock of Switzerland (construction period 1900–1960). With present cost level (continuous line) as well as with dynamic costs (dashed line). *Source:* Jakob et al. (2002).

If the cost decreasing potentials for 2010 due to techno-economic progress are included, a further 500 TJ of efficiency gain (on top of the already large potential), which is achieved by insulating cellar walls and reinforcing the insulation of building exteriors, becomes economic, even if no increase in energy prices is assumed. This accounts for a further 2% of the total heat requirements of this category of buildings, or for 20% of the feasible refurbishment potential of the share of buildings under consideration.

Technological progress and cost dynamics

It is important for investors with large real estate portfolios, but in particular for administrative bodies and politics, that for thermal insulation measures, a techno-economic progress has been observed in the past. Methodologically, this progress can be described by the concept of learning and experience curves. Subsequent to this, new technologies are mostly relatively expensive at the start of their admission to market, but as experience shows the costs decrease by a certain percentage (mostly 10–20%) with every doubling of their application. Energy efficiency measures (in particular constructional ones) show a diverse cost structure. Different deflators had to be applied to the individual cost components, in order to adjust the nominal price development estimated by the companies to the current costs, or rather different cost reductions for the cost components for the

²² A long-term energy price increase of 0.01–0.015 CHF/kWh and a CO₂-tax of 210 CHF/t CO₂ is assumed, see also Jochem and Jakob (2002).

coming two to three decades. More details on cost estimates that are based on the experience curve approach can be found in Jakob and Madlener (2003) or in Jakob and Madlener (2004).

Because of the connection between turned-over quantities and decreasing costs, future price development, as well as technological advances may be influenced to a certain degree. If energy efficiency is promoted by suitable framework conditions (temporally restricted promotion programmes, taxes, export promotion, production cooperations, pooling of demand, etc.), this will enable companies to build up experience, to initialise learning processes, i.e. to produce larger series.

2.6 Conclusions and further perspectives

The present analysis of the residential buildings stock and the possible thermal insulation measures with their cost structures and ancillary benefits demonstrate a complexity of the examined subject, which has been greatly simplified in previous energy economic analyses and models and by environmental interest groups. On the one hand, this led to an underestimation of the costs of conserved energy, i.e. if only insulation material costs are taken into account. On the other hand, the too simplified approach of only taking the current energy prices into account led to the observed, cliché'-like valuations that heat insulation measures showed little cost efficiency and that they could only be integrated into the buildings stock if they were financially more attractive. On the contrary, the analyses suggest the following:

- Thermal insulation measures in buildings with previously non-insulated building envelopes (walls, roofs or cellars) are profitable in most cases, especially if the building owner includes a highly probable increase in energy prices during extended periods of use and the ancillary benefits in his business economic assessment.
- From an energy-economic point of view, additional insulation measures are cost-efficient because ancillary benefits which cannot all be acquired privately (e.g. avoided costs caused by illness or by loss of earnings), as well as avoided external costs with regard to conventional air pollutants (in the range of 0.008–0.034 CHF/kWh) and to greenhouse gas emissions (in the range of 0.045–0.08 CHF/kWh) have to be included in the consideration.

Not investigated in this analysis, but nevertheless worth mentioning, are the further benefits from an energy economic and a macro-economic point of view. This includes the substitution of energy imports with efficiency goods and services produced in the own country, the re-availability of saved energy costs for other economic activities (rebound effect) and newly possible innovations, cost decreases and exports opportunities (politically induced techno-economic progress), as well as additional employment, also in rural and laggard regions.

From the point of view of the present or future, private residential building owners and real estate investors it is necessary to be far-sighted with regard to thermal insulation; the (mostly constructional) investments have a very long technological and economical lifetime from three to more than five decades and it is substantially more expensive to install thermal insulation on a later occasion (up to a factor of 3). A generous thermal insulation system has very low economic risks. Considering risks of increasing energy prices, thermal insulation can be described more as an insurance policy, because the marginal cost curves are relatively flat in the area of current energy prices. The ancillary benefits – which are often not expressed in financial terms or to which not even any attention is paid – can be of the same order of magnitude as the reduction of heating costs. The authors recommend that economic valuation of these ancillary benefits should receive more attention. The induced increase in the value

of buildings, or rather the improved leasing potential (rental income) of thermally insulated buildings, has not been included in the economic valuation of thermal insulation measures by most building owners, investors, but is of fundamental significance for investment decisions due to ever-changing framework conditions (assessment of credit-worthiness by banks, ageing population). Indeed first results from Ott et al. (2006) based on the hedonic pricing method a price effect for buildings meeting the 'Minergie' label of 9% (75%) of the selling price of single-family houses was revealed.

From an energy economic and climate policy point of view, building refurbishments and their large efficiency potential, which come close to being economic, deserve more attention. In comparison to other environmental and climate protection costs, building refurbishment in particular, but also the construction of new buildings, offer large potentials to comparatively low or even negative marginal costs (i.e. profits), especially for renewal as opposed to maintenance.

Based on the experiences and the developments of the last 30 years and based on the results of this study, the following tools and measures stand to reason, in order to develop the existing potentials (see also Jakob and Madlener, 2004):

- The definition of construction standards and their regulation (their legal implementation and control) has effects on several levels: (i) it helps to reduce the specific energy requirements of new buildings with each tightening of standards (ii) it informs about construction practices and identical construction components (e.g. windows, improved insulation materials, rationalised installation) and (iii) it also causes a reduction of the energy requirements of the existing building stock. On the other hand, the standards promote new technological solutions and techno-economic progress through learning and economy of scale effects resulting in further cost reductions for producers and installation businesses, thereby creating new markets. A regular tightening of the construction standards according to technological developments is therefore indispensable.
- Standards and labels of associations, such as the Swiss 'Minergie' label or the German 'passivhouse' standard play an important pioneer role. They give new impulses for producers, environmentally friendly building owners and architects, and thus have an innovation stimulating effect, serve as benchmarks, result in market transparency, but also serve as experimentation field for the next tightening of the construction standards and requirements?
- The avoidable external costs of energy use due to improved thermal insulation are in the range of a few cents of CHF per kWh and the achievable additional co-benefits, which are not privatised, legitimise further federal framework conditions of a fiscal or policy nature, for example the introduction of tax (e.g. the CO₂-tax of the CO₂ law). Adjustments to the tenancy law, which does not consider the accompanying benefits (noise protection, improved indoor air) from the view of the tenant, is also urgently required, in order to overcome the user/investor dilemma. The communication of net rents (including extra charges) is a first step in this direction.
- The results of this study are very extensive with regard to costs and energy-related benefits. Including first results on co-benefits expressed in financial terms, they have been and they still are being processed further. A summarising and more easy publication for a target audience of policy makers, designers of promotion programs, architects, builders, house owners and interested groups has been produced in French and German (see Jakob et al., 2003 b, c) Further channels such as the communication campaign 'bau-schlau' starting in 2004, documentation for further education, information leaflets, technical journals, construction magazines are suitable for further communication.

- The extent of the ancillary benefits and co-benefits of thermal insulation measures and their expression in financial terms are barely known and poorly analysed. In order for these benefits to be naturally included when making investment decisions, further research is necessary in this area. Currently (2003/2004) the programme 'Energiewirtschaftliche Grundlagen', EWG (energy-economic foundations) of the Swiss Federal Office of Energy (BFE) is tackling this issue in a research project (Ott et al., 2004).

In general, the results give reason to be optimistic because the innovation loop "standards/-innovation/cost reduction", the imitation and diffusion of the standards for new buildings by the renovation investments and the future inclusion of ancillary benefits form promising starting points for a sustainable development in the residential buildings sector.

Acknowledgements

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CHAPTER 3

RIDING DOWN THE EXPERIENCE CURVE FOR ENERGY-EFFICIENT BUILDING ENVELOPES: THE SWISS CASE FOR 1970-2020 (JAKOB AND MADLENER, 2004)

This Chapter 3 was published in the International Journal of Energy Technology and Policy, 2(1-2): 153-178 and is referred to as Jakob and Madlener (2004).

Abstract

Energy efficiency potentials of building envelopes are significant and still largely untapped. Increasing concerns of policy-makers about non-sustainable energy use and climate change spur a growing research interest in this area. This paper fills part of the existing knowledge gap by focusing on experience curve (EC) aspects of energy efficiency measures that concern state-of-the-art insulation methods, materials, and windows. The analysis addresses some of the difficulties and peculiarities of applying the experience curve concept to energy efficiency technologies. We also report on some of the more general technological trends and dynamics of market diffusion of innovative energy conservation technologies for the building envelope. The results derived from historical data analysis point to significant techno-economic progress made over the last 30 years, and demonstrate the basic applicability, merits and limitations of the experience curve concept for energy policy design and impact analyses concerning building envelopes. We conclude from our analysis that, apart from the energy conservation potentials offered, building standards and labels can be important drivers for techno-economic progress, and that experience curves can provide some useful guidance for targeted and effective policy measures.

3.1 Introduction

Building envelopes bear significant and to a large extent still untapped energy efficiency potentials, which strongly depend on the prevailing climatic, socio- and techno-economic, institutional, and regulatory framework conditions. Given increasing political efforts to curb unsustainable energy demand levels, e.g. in order to reduce fossil fuel import dependence, local pollutant emission, and global greenhouse gas emission, these potentials become the focus of heightened interest both from researchers and policy-makers alike. While the scientific literature provides numerous papers from various disciplines that have focused on different aspects of energy-efficient buildings and related policy measures (see Jakob and Madlener (2003) for a brief overview), much less evidence can be found on the diffusion of energy efficiency technologies related to the building envelope in general, and experience curves (EC) in particular.

The residential and service sectors alone account for more than 40% of the final energy consumption in the European Union (CEC, 2002) and in Switzerland (Jakob et al. 2002). The exploitation of the existing energy efficiency potentials hidden in building envelopes to a large extent comes at either no, or relatively low, additional direct costs (calculated as annualised or present value total costs of the investment minus energy cost savings). For instance, for Switzerland it has been estimated that based on standard net present value investment evaluation criteria, for *existing buildings built prior to 1980* about 30% to 50% of the energy consumption could be conserved with measures considered as cost-efficient (reduction from 450 MJ/m²a to 250–300 MJ/m²a), and an approximate additional 20–30% would come at low cost. For *new buildings*, an estimated 20–30% of the measures can be realised at low cost (Jakob et al., 2002; Binz and Schneider, 2000).

However, many *barriers* still exist that prevent a more rapid diffusion of energy efficiency technologies and thus the reaping of further experience curve gains, and even seemingly ‘no-regret’ (or ‘minimal regret’) options, i.e. options that are basically cost-efficient if judged by standard economic investment evaluation criteria, yet remain under-utilised (so-called ‘efficiency gap’ or ‘energy paradox’; e.g. Jaffe and Stavins (1994) and Thompson (1997)). A sound understanding of the prevailing barriers and drivers can, on the one hand, help to better understand the market and learning system involved and, on the other hand, help to predict future achievable progress ratios more accurately. *Important barriers* are: (a) energy efficiency investments in the building envelope typically have an ‘add-on’ character (i.e. they are inessential for the basic functioning and utilisation of the object); (b) the building stock turnover is relatively slow and by far not every building envelope refurbishment is done for achieving energy efficiency improvements (in Switzerland, for example, over the last 15 years, 45–60% of the façades from buildings erected prior to 1975 were renewed, but most renewals comprised façade painting only). Other barriers include budget constraints, landlord-tenant dilemmas, and appearance protection of outstanding buildings. *Important driving forces*, in contrast, include construction deficiencies (e.g. problems with mould in older buildings), comfort considerations, active building stock management, and certain economic considerations (e.g. prevention from accelerated depreciation).

Experience curves, i.e. curves that depict experience-driven cost reductions over cumulative production levels, provide a useful and in public policy still widely under-utilised analytical tool for assessing the historical and expected future performance of technologies in markets, and can help to shape energy, environmental, climate change, and other policies²³.

The assessment of experience curves of building-envelope-related energy efficiency measures and potentials is complicated by the fact that typically one has to deal with a compound system (impact and interplay of materials and building components used), varying investment decision practices, and severe data limitations. Furthermore, the transferability of experiences from one country to others is rather limited due to differences in climate, tradition, construction costs, building codes, insulation standards, etc.

²³ Pioneering work on the experience-curve phenomenon has been undertaken by the Boston Consulting Group in the 1960s (BCG, 1968, ‘Perspectives on experience’), based on earlier studies done, for example, by Wright (1936) on the aeroplane industry. BCG defined the term ‘experience curve’ for curves that relate total cost and cumulative quantity, a definition that we will also follow here. For more recent work see for example IEA (2000). Experience Curves for Energy Technology Policy, OECD/IEA, Paris; Neij, L. (1997) ‘Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology’, Energy Policy, Vol. 23, pp.1099–1107.

In this paper, we analyse technological progress and marginal cost developments for energy efficiency measures related to the building envelope, drawing heavily from a recent and extensive techno-economic study for Switzerland (Jakob et al., 2002). In particular, we study learning effects concerning innovative products (e.g. insulation materials, construction elements) and processes (e.g. concerning production, planning, logistics, and mounting) relevant for a more energy-efficient building envelope, including windows. The results from our analysis are then put into a somewhat broader perspective, in order to improve our understanding of experience curves related to a more energy-efficient insulation of the building envelope, and how this can be used in policy design and impact analyses. Many of the insights gained from the Swiss experience and prospects can be taken up and adapted to other countries, provided that the differences in the framework conditions are appropriately taken into account.

This chapter is organised as follows: Section 3.2 introduces the basic concepts employed and deals with the peculiarities of experience curves in the context of energy efficiency technologies applied to the various components of the building envelope (walls, windows, etc.). Section 3.3 provides an overview of the techno-economic and institutional progress that has been made in this field in Switzerland and elsewhere over the last three decades. Section 3.4 addresses the impacts of different diffusion dynamics (investment paths), while Section 3.5 delivers some policy recommendations and concludes.

3.2 Applying the experience curve concept to energy efficiency measures for the building envelope

3.2.1 Cost reduction potentials through economies of scale and scope and learning effects

In this section, we address issues of economies of scale and scope, and of learning and mass production. *Economies of scale and economies of mass production* refer to unit cost reductions that can be reaped from production level increases at which higher operational efficiencies can be achieved and the fixed costs better spread among the products produced. While the former is more related to the plant level (firm size), the latter focuses on the production technique. *Economies of scope*, in contrast, refer to cost reductions that can be reaped from synergies between production of different products within the same company, e.g. because of joint use of production facilities and inputs, joint marketing activities, joint administration, or because one product yields another as a by-product. Learning curve effects refer to the phenomenon that unit production costs typically decrease over time. Sometimes, the term learning curve is used synonymously with experience curve (or progress curve, or learning-by-doing curve), and sometimes learning curve effects are considered to be restricted to learning effects of the workforce, in contrast to experience curve effects that comprise learning effects of the whole firm (i.e. including technical and/or managerial improvements of product design and/or production process), or the whole sector. Table 3 provides an overview on the relative importance of different categories of techno-economic progress of energy efficiency and end-use technologies used for buildings (based on expert judgement).

Energy efficiency investments concerning the building shell often consist of a combination of industrially fabricated products on the one hand, and the installation/application/mounting of these products on the construction site on the other hand. Depending on the relative cost share and the

stage of the innovation process, different experience curve effects prevail. Whereas for the first cost component mentioned, economies of mass production and economies of manufacturing plant scale are typically more important, for the second cost component, learning effects (e.g. leading to a change of production method) as such tend to dominate. However, the learning component can be important also for the fabrication of products, especially if they are at an early stage of innovation (e.g. enhanced insulation thickness, window frames made of wood-based compound materials, vacuum-based insulation panels, foil-inserted glazing, and the like).

Table 3 Assessment of the actual and future (until approx. 2020) cost reduction impacts of selected investments in thermal insulation and energy conversion technologies (+++ major, ++ medium, + minor)

Technology categories and selected examples	Learning effects*	Economies of mass production	Economies of plant scale
Building envelope / Heat insulation			
'Traditional' insulation materials (mineral fibres, polystyrene/polyurethane foams)	+	+	+
'Traditional' window glazing (double/triple)**	+	+ (double) ++ (triple)	+
Innovative window glazing (vacuum- or foil-based)	++	+	+
Design and on-site application of insulation materials, components, and auxiliaries	+++	++	+
Pre-fabrication of construction elements (e.g. walls and roofs for wooden buildings)	++	++	+
Window frames (compound materials)	+++	++	+
Passive energy houses	+++	++	+
Vacuum insulation elements	+++	+++	+
Energy conversion			
Boilers, burners	++	+	+
Air renewal systems with heat recovery	++	++	+
Heat pumps	++	+++	+
* Assuming targeted searches for efficiency improvement potentials.			
** Improvements concern mainly the optimisation of the ratio between solar energy gain and thermal conductivity/heat loss; further heat loss reductions of the glass can only be achieved with innovative window glazing.			

Source: Based on expert judgement; adopted from Jakob and Madlener (2003).

3.2.2 *Conceptual issues regarding the use of experience curves for the building envelope*

Usually, in an energy context, experience curves describe the relation between specific costs of energy generated (or converted) and the cumulative output of the generating or converting technologies studied, measured in capacity units such as kW, or number of units produced such as kWh, and the like. In contrast, energy efficiency technologies and measures do not *provide* energy, but rather help to *conserve* it (i.e. to reduce energy demand), which calls for the definition of a reference (or baseline) for the measurement of the amount of energy conserved, or energy efficiency gained, respectively.

The cumulative area of façades, for instance, on which state-of-the-art heat insulation has been applied, could be a measure for the (cumulative) output of energy efficiency investments. However,

such a measure would not take into account the increasing energy efficiency of façade insulation over time (technical progress). As a matter of fact, the costs and energy efficiency of a particular insulation measure for the building envelope including windows depend mainly on the U-value, which in turn depends on the thickness of the material used²⁴. Consequently, some energy efficiency measure has to be included into the characterisation of the specific cost and/or the cumulative output of a particular technology as well. Table 4 provides an overview of and differences between typical (cumulative) output and specific cost categories for energy conversion (here: electricity generation) technologies on the one hand, and energy efficiency measures/technologies relevant to the building envelope on the other hand.

Table 4 Comparison between (cumulative) output and specific cost categories, and between electricity generation technologies vs. building envelope insulation measures/technologies

Category	Electricity generation technologies	Building envelope insulation measures / technologies (incl. windows)
Output	Electrical capacity, homogenous good, independent of technical characteristics and of stage of development of the plant	m ² of applied insulation or windows, energy performance depending technical characteristics and of stage of development
Cumulative output	Cumulative installed capacity kW _{el}	Applied m ² @ technical characteristics Cumulative kWh _{conserved}
Specific costs	Euro/kWe Euro/kWh _{produced}	Euro/m ² @ technical characteristics Euro/kWh _{conserved}

Source: Own illustration.

The cost of the energy conserved²⁵ not only depends on the maturity of the technology concerned, but also largely on the thermal quality standard actually chosen (insulation thickness, U-value, etc.). In other words, the costs of conserved energy can be low at an early stage of innovation because the consumers prefer low insulation thickness, whereas later on, when the cumulative output has grown further (and consequently the experience curve concept would suggest lower specific costs), they may in fact have risen because of an increase in insulation thickness used (e.g. due to legal requirements and/or higher prices/price expectations).

Let us assume for a moment the stylised case where the insulation thickness is chosen in such a way that the marginal cost of conserved energy equals the marginal cost of heat generation, and that the latter would remain constant over time. In this case, the economic agents would adjust the insulation thickness in line with the techno-economic progress experienced (if insulation gets less expensive, then more insulation can be applied to reach the economic optimum) and, as a consequence, the observable cost of conserved energy would remain constant over time. Likewise, the observable specific costs and insulation thicknesses would not follow a single experience curve, but rather switch from one to another in a subsequent manner (see Figure 11). Of each of these different experience curves, however, only a short piece can be empirically observed, as insulation thicknesses

²⁴ The U-value, expressed in W/m²K, is a measure for the thermal loss of materials or components used in the building sector. Albeit the energetic quality of a particular efficiency measure cannot be derived from the insulation thickness alone, the latter is an important determinant of the U-value. Note that insulation thickness and U-value are inversely related to each other.

²⁵ Note that we use the expressions 'cost of additional energy efficiency' and 'cost of conserved energy' synonymously in this paper. Note further that the 'cost of energy conserved' is not the same as 'avoided cost of energy conserved' (i.e. the latter refers to reduced expenditures for energy), and should not be confused.

and energy efficiencies of windows changed gradually and not in major steps. Indeed, since it is already difficult to empirically determine the present marginal cost curve (or the wall insulation cost as a function of insulation thickness), for practical reasons, it is almost impossible to determine historical marginal cost curves.

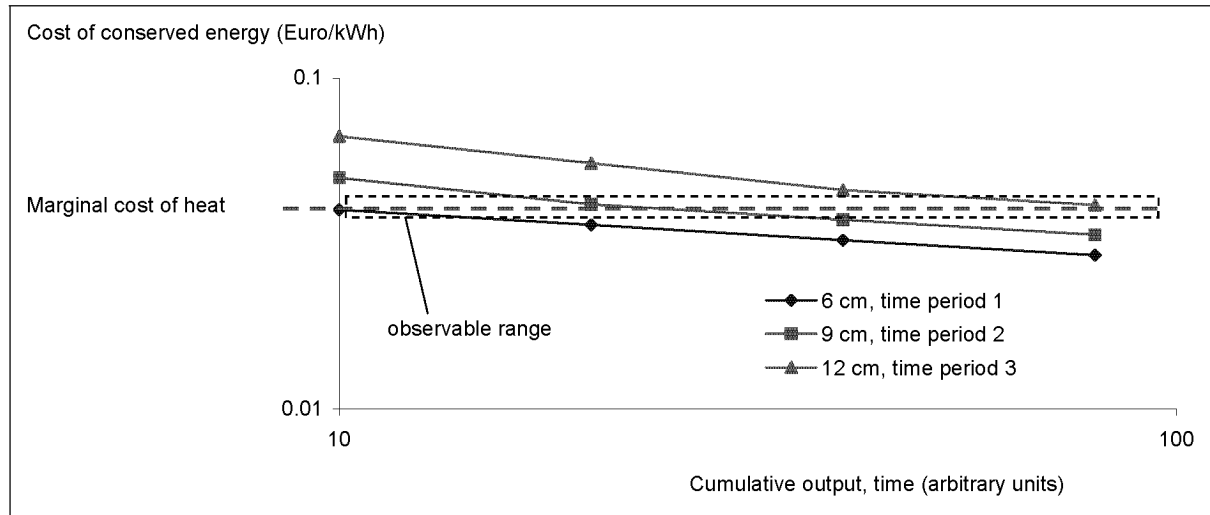


Figure 11 Experience curves for different insulation thicknesses vs. marginal cost of heating (stylised)
Source: own illustration

The bottom line of this exposition is that the cost of conserved energy is not necessarily a good indicator to be used in experience curve considerations. However, there might be cases where the experience curve concept is applicable also for energy efficiency measures whose characteristics gradually evolve over time (such as standard wall insulation thickness, which increased steadily in the past). In any case, it is important to assess the institutional, regulatory, techno-economic, societal and other framework conditions when interpreting relations between costs, technical progress, and cumulative output. In other words, it might be a good idea to separate innovation introduction phases where the marginal costs of energy efficiency rise (e.g. due to more stringent codes and standards which first lead to higher cost but also to higher energy efficiency) from consolidation phases where a downward-sloped experience curve can actually be observed. In the following two subsections, we first describe cases where the specific costs of energy conserved can be used, followed by two proposed alternative methods for cases where they are not suitable.

Method 1: Joint consideration of specific cost and technical characteristics

Let us define the cost of energy efficiency (or cost of conserved energy) at time t , $C_{EE,t}$, as:

$$C_{EE,t} = \frac{a \cdot (I_t - I_{0,t})}{(U_0 - U_t) \cdot HDD_t \cdot 24} \quad (5)$$

where a is the annuity factor (that depends on the lifetime and interest rate assumed), $(I - I_0)$ denotes the additional investment costs at time t (Euro/m²) referred to the reference efficiency level U_0 , U is the resulting U-value of the efficiency investment considered (in W/m²K) and HDD stands for

heating degree days²⁶. Note that in the experience curve concept I_0 and U_0 correspond to the construction standard at $t = t_0$, e.g. a wall without insulation.

Such defined costs of energy efficiency can then be used in an experience curve approach for the following two cases: First, for clearly distinguishable technologies, such as double-glazed non-coated windows, double-glazed coated windows, triple-glazed coated windows, etc. Second, when a new market is created, or a certain standard of a technology is needed or applied due to new legal requirements, independent of the marginal cost of energy conservation or heat generation. For example, the introduction of the heat protection ordinance ('Wärmeschutzverordnung'²⁷) or the passive energy house label in Germany, or the MINERGIE label for energy-efficient buildings in Switzerland, created new markets that made it necessary to apply innovative technologies, or more energy-efficient versions of existing products and methods. This caused an augmentation of the marginal cost of energy efficiency in the short term. Later the costs decreased again, and it is exactly this cost reduction process that can be assessed by the experience curve concept. In mathematical terms, in both cases, the experience curve can be formulated as follows:

$$C_{EE} = c \cdot Y_{cum}^b \quad (6)$$

where C_{EE} denotes the marginal cost of energy efficiency (in CHF/kWh, €/GJ etc.; 1 Swiss Franc (CHF) is equal to about 0.66 Euros (€)), Y_{cum} the cumulative output (in m² applied, kWh_{conserved} etc.), and b and c are coefficients to be empirically estimated. Note that a cost decreasing experience curve effect can only be detected if $b < 0$, and that Y_{cum} , expressed in kWh conserved, is calculated as the sum of the denominator of equation (5) times the area of insulation applied in each year, A , i.e.:

$$Y_{cum}^{kWh} = \sum_{t=1}^T [A_t (U_0 - U_t) \cdot HDD \cdot 24] \quad (7)$$

From this the progress ratio, pr , can be derived as $cum\ pr = c \cdot (2Y_{cum})^b / c \cdot Y_{cum}^b = 2^b$.

Method 2: Separate consideration of specific cost and technical characteristics

If the energy quality of the building envelope is chosen according to some standard economic optimality condition (e.g. the marginal cost of energy efficiency equals the marginal cost of heat generation), or if the cost of conserved energy is even rising over time and over cumulative output despite some techno-economic progress (implying a shift to the right on the marginal cost curve, so that per m² more energy is being saved), we propose the following alternative method that considers specific costs and technological characteristics separately.

If the marginal cost of (additional) energy efficiency remains constant over time, or over cumulative output, then this does not necessarily mean that there is an absence of techno-economic

²⁶ The heating degree days (HDD) concept is useful for determining the energy requirements for heating purposes. It takes into account that at days below a certain daily mean temperature a building needs to be heated in order to maintain a specific indoor temperature. Such days are called heating days. The HDD for a given period of time are computed as the sum of all differences between the mean temperature of these heating days and some chosen reference indoor temperature (e.g. 20°C, definitions vary).

²⁷ WärmeschutzV (1995) Verordnung über einen energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutzverordnung – WärmeschutzV) vom 16. August 1994, BGBl. I S. 2121ff. This ordinance has been replaced in the meantime by the Energieeinsparverordnung (2001). Verordnung über energiesparenden Wärmeschutz und einergiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung – EnEV) vom 16. November 2001, BGBl. I Nr. 59, 21, November 2001, S. 3085ff.

progress. Indeed in economics in general and for energy efficiency in particular, it is often the case that technological progress leads to a higher utility level at constant cost. In these cases, techno-economic progress could be described by insertion of equation (6) into equation (5), yielding:

$$I - I_0 = c_1 \cdot Y_{cum}^{b_1} \quad (8)$$

$$U - U_0 = c_2 \cdot Y_{cum}^{b_2} \quad (9)$$

If $b_1 - b_2 = 0$, then the marginal cost of energy efficiency is constant; in contrast, if $b_1 - b_2 < 0$, then some techno-economic progress has occurred that is dependent on cumulative output (and which thus can indeed be tackled by some experience-curve-based energy policy measures).

3.2.3 *Established vs. pioneer markets*

When assessing new and innovative technologies, pioneer and niche market phenomena can be observed. In what follows next, we briefly discuss some empirical evidence found for the case of exterior wall insulation and windows in Switzerland. Figure 12 depicts the price differences per square metre (compared to an insulation thickness of 12 cm) charged by various Swiss building companies in relation to the thickness of the wall insulation concerned. Data were gathered in a survey in which the price as a function of the insulation thickness was asked for. Thus, the data do not represent real project prices, but rather systematic 'close to the market' offer prices. As can be seen from Figure 12, prices are quite similar in the range between 8 cm to 16 cm, which corresponds to today's most commonly used insulation thickness (conventional 'standard' range, left of the dashed line), but they vary much stronger beyond a thickness of about 16 cm (innovative 'above-standard' range, right of the dashed line). This can be explained by the following two factors:

- Having 12 cm as the most common insulation thickness, more than 15 cm is applied quite rarely, and the façade companies have not yet gained sufficient know-how and experience both in carrying out such façade applications and in competitive (marginal) cost calculation, so that it can be safely assumed that some precaution surcharges (risk premiums) are included in the price quotes.
- The market for high-efficiency building envelopes is only about starting to develop, both on the supply and the demand side. Indeed, up to now, most architects and planners were not yet very well informed about best available technologies and best practice charges for increased insulation thicknesses, and neither were the consumers.

At present, high insulation thickness is used mainly in niche markets where prices are price-policy-driven rather than cost-driven. However, it can be expected that the more the demand for increased insulation thickness will rise and the more architects, planners and investors are informed about best practice costs, the more the prices will decline towards the bottom end of best practice prices (companies D, F, L, N and O in Figure 12). Using the definition of CEE given in equation 5, it becomes evident that the cost of energy efficiency would drop considerably if this happens, see Jakob and Madlener (2003) and Jakob et al. (2002) for more details.

Also, in the case of windows, the established market segment of plastic-framed windows shows a much less pronounced cost increase as a function of improved energy efficiency than the pioneer market for wood-based compound frames, see Jakob and Madlener (2003) and Jakob et al. (2002) for more details about these empirically based findings.

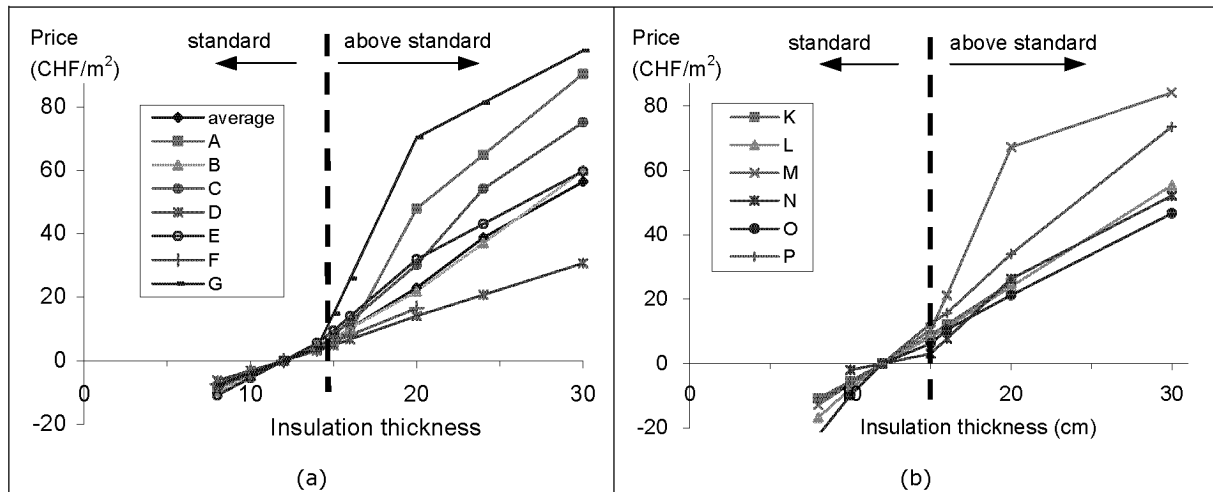


Figure 12 Additional price charged by different Swiss building companies (tagged A–G and K–P) for various wall insulation thicknesses; relative to standard insulation: (a) compact façades, (b) ventilated façades. Source: Based on Jakob et al. (2002).

3.3 Techno-economic progress over the last 30 years

The legal and institutional framework conditions regarding energy standards determine to a large extent the techno-economic progress in the different countries. For example, it can be observed that in countries with legally binding but not very ambitious building standards, new buildings are insulated much less and windows have higher thermal losses than in countries with more rigorous standards (see Jakob and Madlener (2003) for a compilation of wall and roof insulation thicknesses in Europe).

In Europe, for instance, only a few large international window glazing manufacturing companies exist today. Nevertheless, the different local and national subsidiaries of these international corporate groups typically do not produce their best available technology (BAT), but only the level that meets the national or regional insulation standards and/or traditions. For example, while in Austria and Switzerland coated and inert-gas-filled glazing almost became the standard glazing technique during the early 1990s, the market share for this kind of window in Germany was only about 10%. Only the announcement of a building insulation ordinance (Wärmeschutzverordnung²⁸) in Germany in 1995 triggered the rapid and accelerated market penetration of this kind of insulation glazing. The rapid diffusion was supported on the supply side, because the reduction in regulatory uncertainty induced the glazing companies to invest into production facilities that enabled to produce coated glazing at much higher output rates, and – because of both mass production effects and production type effects (change from batch production to serial production) – at lower costs (e.g. Blessing, 2001).

3.3.1 Evolution of relevant framework conditions – the Swiss experience

Deeply impressed by the two oil price shocks of the 1970s and their economic consequences, the Swiss authorities and professional associations (much like in many other countries) began to worry

²⁸ WärmeschutzV (1995) Verordnung über einen energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutzverordnung – WärmeschutzV) vom 16. August 1994, BGBl. I S. 2121ff. This ordinance has been replaced in the meantime by the Energieeinsparverordnung (2001). Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung – EnEV) vom 16. November 2001, BGBl. I Nr. 59, 21, November 2001, S. 3085ff.

about the increasing energy consumption of the building sector and, accordingly, tried to promote energy efficiency improvements of the building envelope. To a limited extent, such improvements were also pushed by the construction industries, and partly pulled from the demand side through private and public project developers.

While the first oil crisis in 1973–1974 led to a certain awareness about the importance of energy efficiency measures and some early action, only the second oil shock of 1979 led to the implementation of legally binding standards in several Swiss cantons. These were predominantly focused on individual construction elements (walls, roof, windows) though. In 1988 then, the Swiss Association of Engineers and Architects (SIA) published a standard based on these construction elements (SIA Standard 180) and, in addition, a unitary building standard on how to calculate the energy demand of buildings as a whole (SIA Standard 380/1), together with two benchmark levels (limit and target values) for energy demand²⁹. In the mid-1990s, SIA published a so-called ‘reduction path’ (Absenkpfad) for energy requirements of buildings and the federal administration encouraged the harmonisation of energy-relevant legislation for buildings (see Frauenfelder et al., 2002). Meanwhile, the latest edition (2001) of SIA Standard 380/1 also contains an adaptation to European standards (SN EN 832) and serves most of the cantons for formulating their legislations (MuKE, 2000).

As a consequence of all these actions taken, the energy-related quality of the building insulation and windows applied improved continuously over the past thirty years (cf. Figures Figure 13 and Figure 15), while the specific energy demand for space heating of new buildings has decreased accordingly. In fact, the technical progress of windows developed even faster than the legal requirements or the standards that were set by the SIA. As a reaction to rising difficulties in enforcing and tightening command-and-control measures aimed at raising the energy efficiency of buildings, some of the cantonal authorities put more weight on motivation, stimulation, and incentive-based measures. In 1997, they co-founded the MINERGIE association, and a MINERGIE label (a registered trademark) and standard were created, with the goal of promoting further improvements regarding the energy requirements of buildings through labelling.³⁰ It is estimated that only five years after its introduction, the market share of new single-family MINERGIE houses has already reached some 5–8%. Mainly three factors are responsible for the great success of the MINERGIE concept: (a) the architects’ and planners’ freedom on how to achieve the energy demand requirements (optimising both building-envelope-related and/or energy-efficient or renewables-based end-use technology choices, i.e. a performance- instead of a component-oriented approach); (b) the linked promotion of co-benefits associated with improved building envelopes and the installation of air renewal systems (e.g. increased comfort of living); and (c) in the MINERGIE buildings niche market owners and tenants of new buildings show a non-negligible willingness to pay for these co-benefits, as first results from an ongoing survey evaluation confirm (Ott, Baur and Jakob, 2006). Thus, MINERGIE increasingly becomes an issue also for the real estate sector.

²⁹ See also www.sia.ch (SIA) and www.energycodes.ch (Swiss Energycodes)

³⁰ See www.minergie.ch; SISH (1997) *Minergie: Standard für energieeffizientes Bauen und Sanieren* (Minergie: Standard for Energy-Efficient Construction and Revitalisation; in German), Tagungsunterlagen des 3. Herbstseminars, SISH (Schweizerische Ingenieur- und Technikerschule für Holzwirtschaft)/BVE (Bau, Verkehrs- und Energiedirektion des Kantons Bern), Biel; and more recently SISH (2002) Tagungsunterlagen des 8. Herbstseminars, *MINERGIE für Gewerbe-, Industrie- und öffentliche Bauten*, Biel: Schweizerische Hochschule für die Holzwirtschaft (SH-Holz), 31. Oktober 2002.

Many of the cantons and many banks have since then defined the MINERGIE standard as a prerequisite for receiving financial support or more favourable conditions, respectively, for the construction of new and the refurbishment of existing buildings. Recently, the MINERGIE standard has been refined in various ways (minimum standard also for the building envelope, introduction of a more ambitious standard that reflects the German passive house standard, extension to service and industry sector buildings). It can be expected that the further development and expansion of the MINERGIE market will help to ratchet down the energy requirements of the Swiss building stock.

Finally, the obligations entered under the Kyoto Protocol (UNFCCC, 1997) and related national policy programmes ('EnergieSchweiz') and laws (e.g. Swiss CO₂ Act 2000), respectively, are important driving forces, as are the above-mentioned steps that have been taken to foster innovation in the building sector.

3.3.2 Techno-economic progress – some empirical evidence for Switzerland

A separate assessment of the different cost components seems advisable. In this section, we will discuss the techno-economic progress that has been made in Switzerland over the last three decades with respect to energy efficiency of the building envelope. Because energy efficiency measures in this field typically consist of several cost and/or technical components, we decided to provide illustrative examples for both façades and windows. Similar improvements have been achieved for inclined and flat roofs, ground floor or basement wall insulations, as well as for (outer) doors, as can be seen from Table 5.

Table 5 Past development of insulation thicknesses of different construction elements (mm)

Construction element	< 1960	1961-1965	1966-1970	1971-1975	1980	1985	1990	1993	1995	1997	2000
Inclined roof			50	75	90	100	105	117	129	129	135
Compact façade					60-80	75	84		91	96	108
Flat roofs	30	40	50	60-80	80-100		110		120		140
Basement ceiling				20	30		40				

Source: Adopted from Jakob et al. (2002), based on data from a leading Swiss insulation manufacturing company.

Façades

Figure 13 depicts the development of the standard building envelope insulation thickness applied by a sample of Swiss façade construction companies. As can be seen, the insulation thickness has increased by a factor of at least three (!) over a time span of thirty years (the development for roofs has actually been very similar). As a consequence, the U-value of walls has decreased from about 0.9–1.3 W/m²K (historical value with barely any insulation) to about 0.5–0.6 W/m²K (for 4 cm to 6 cm of insulation) and about 0.27–0.3 W/m²K (for 12 cm of insulation). The *up-scaling of insulation thickness* was quite similar for new buildings and the refurbishment of existing buildings, provided some insulation was applied in the latter case (many refurbishments did not comprise insulation, but only wall painting; see Jakob and Madlener, 2003).

Apart from these similarities between new buildings and the renewal of existing buildings, important differences with respect to standards and building quality among individual building

owners can be observed, too. Indeed, a recent survey concerning specific energy consumption of a sample of more than 1000 new buildings in thirteen Swiss cantons revealed wide variation among individual buildings and systematic differences between some of the cantons (Brühlmann and Tochtermann, 2001). A follow-up study currently being undertaken by a Swiss consulting firm investigates the reasons for these differences and seeks for the determinants of the energy-related quality of buildings' constructions achieved (Kaufmann and Dettli, 2002)). This study indicates that not only the legally binding requirements influence the energy consumption of new buildings, but also the implementation and enforcement, and accompanied policy measures such as information, the support of labels, and continued educational efforts.

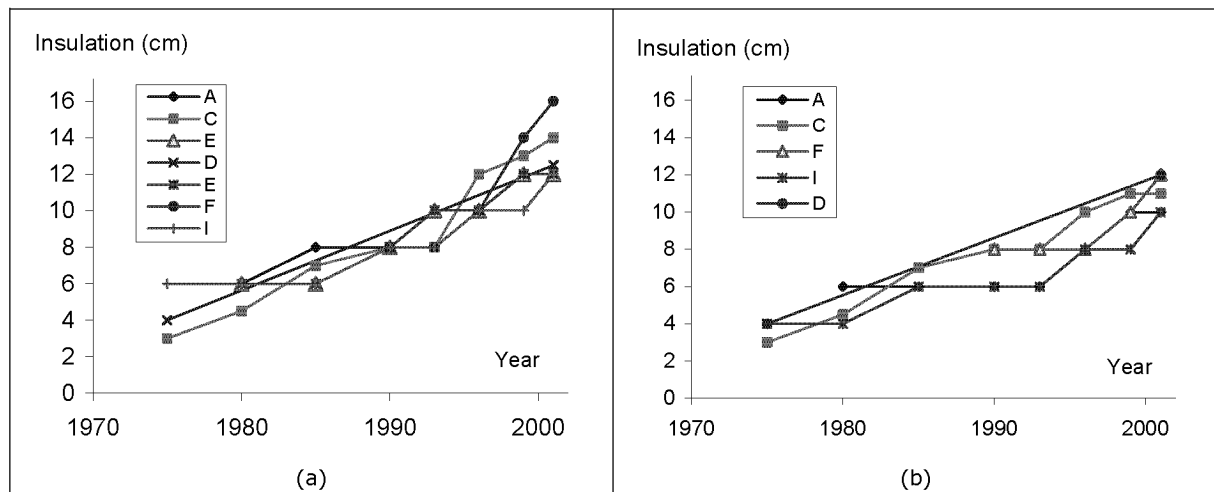


Figure 13 Thickness of the standard building envelope insulation (case of ventilated façades) applied by various Swiss companies, 1975–2001: (a) new buildings, (b) refurbishment of existing buildings. Source: Jakob et al. (2002), based on a sample survey among ten Swiss companies.

Over the last 20–30 years, improvements of wall insulations to meet higher standards or sterner legal requirements were mainly realised by increasing the insulation thickness, and less by the improvement of the thermal conductivity (λ -value), which decreased by about 8–10% per decade. However, for innovative foam-based insulation materials (e.g. BASF's Neopor®), further improvements of between 20% to 40% are expected. Furthermore, public and private R&D in very promising vacuum insulation elements is currently ongoing.

Figure 14 illustrates the techno-economic progress of wall insulations that has been made in Switzerland over the past 15 years. The price increase of the insulation material polystyrene after the mid-1980s and in the early 1990s was caused by a continued boom of the economy in general, and of the real estate market in particular, and also by a higher price of crude oil (which is an input for the polystyrene production). After 1993, continued price decreases for the insulation material could be observed again. The total façade insulation costs (i.e. including the application and the connection to other construction elements) decreased as well, namely from 133–149 CHF/m² in 1985 to 115–135 CHF/m² in 2001 (real 2000 prices), while the insulation thickness increased further. From this resulted an annual decrease of 0.6% in real prices per m² of façade insulated over the period 1985–2001, while the insulation thickness doubled over the same period (cf. Figure 14). Expressed as a reduction in heat transmission losses of the wall as a whole, this implies a technical progress rate per annum of about 3% (the U-value dropped from about 0.5 W/m²K to 0.3 W/m²K).

By assessing the temporal development of the cost structure, one can deduce that the observed total cost decrease of façade insulation was not at all caused only by a decrease in cost for the insulation materials. First of all, the cost share of the insulation material is quite low (between 15% and 25%). Second, the cost of the insulation material decreased only modestly. Learning effects by the applying staff and technical progress of auxiliary material (e.g. adhesives, mechanical fixations) helped to reduce these cost components and to decrease labour assignments from some 2.1 h/m² to 1.7 h/m² between 1980 and 2000³¹.

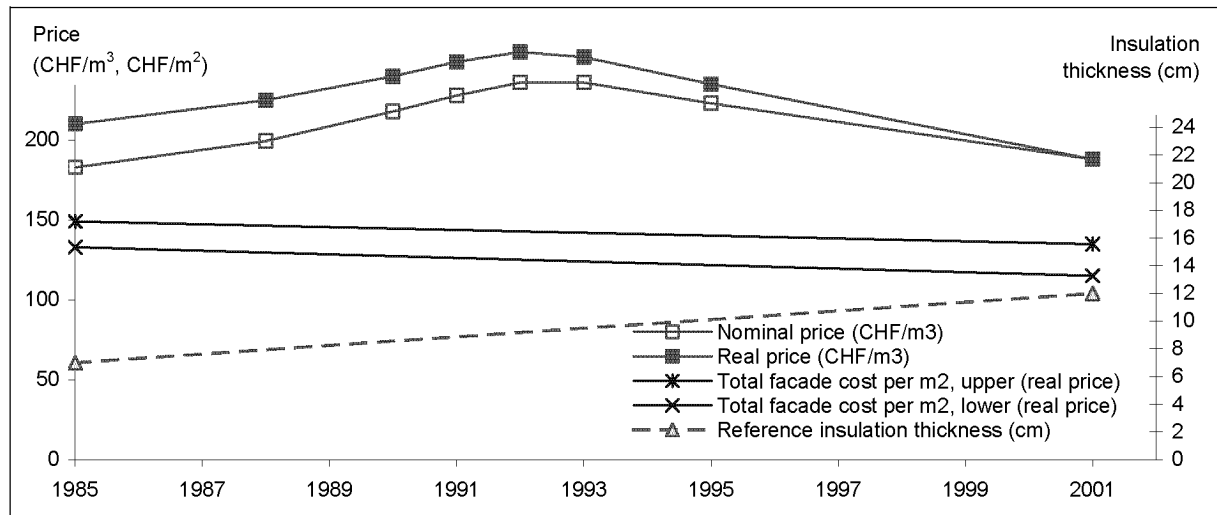


Figure 14 Historical price trajectories for compact façade heat insulation made of polystyrene cellular plastics versus reference wall insulation thickness 1985–2001, Swiss Canton of Zurich (nominal and real 2000 prices). Source: Adopted from Jakob et al. (2002), based on an interview held in 2001 with experts from the Swiss building insulation company Marmoran AG

In order to perform experience curve calculations, the yearly or cumulative output of the assessed technology must be known. Unfortunately, no exact figures on the square metres of façade insulation applied were available to the authors for Switzerland. Experts estimate, however, that the amount was roughly constant (if one ignores short-term and business cycle fluctuations). Since the early 1970s, the cumulative number of square metres of façade insulation doubled five to six times (and about once since 1985).

Window glazing and windows

Windows provide a good example for technical progress that occurs over long time periods (decades) at roughly constant, or even decreasing, nominal prices. Based on an empirical investigation, Figure 15 depicts that the U-values for window glass have decreased from some 6 W/m²K in 1950 (single glazing) to 3 W/m²K in 1960, and 1.8–2.2 W/m²K (triple glazing, 1980s), whereas the U-values for coated and inert-gas-filled double glazing have come down from 1.3–1.6 W/m²K in 1980 to some 0.9–1.1 W/m²K (double glazing) to 0.5–0.7 (triple glazing) as of today. This is equivalent to a technical progress rate of approximately 3.3% per annum over the period 1970–2000.

³¹ Methodological indication: the cost structure was used as well to perform real price calculation. For the insulation materials the producers' price index was used, whereas for the rest of the costs the construction cost index for residential buildings was employed.

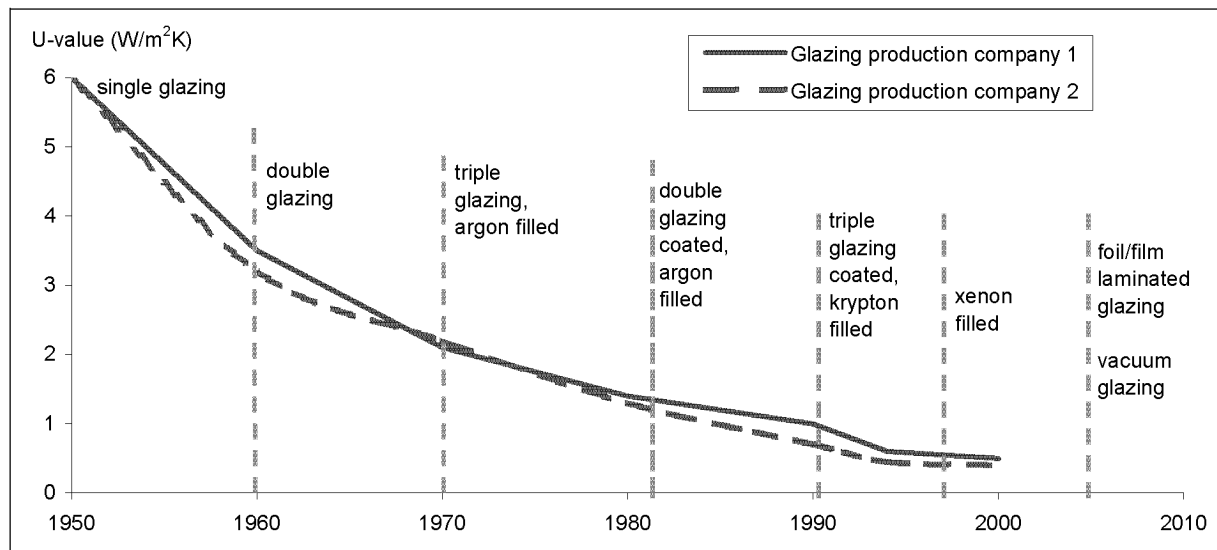


Figure 15 Development of the U-values of window glazing (i.e. w/o frames) from 1950 to 2000, and approximate market introduction of various window-glazing technologies. Source: Adopted from Jakob et al. (2002) and Binz and Schneider (2000), based on data from two leading Swiss glass manufacturing companies.

Note that the curves depicted in Figure 15 do not allow any direct conclusions for the U-value of the window as a whole, as this also depends on the share of the frame relative to the total window area, and also on the technical characteristics of the frame. However, in the past the U-value of the glazing very much dominated that of the whole window, and only when U-values for the glazing dropped below those for the frames (1.4–1.6 W/m²K for wooden frames and 1.1–1.9 W/m²K for plastic frames), attention paid to the frames somewhat increased. Indeed, nowadays the window and frame manufacturers need to catch up in order to keep abreast with the pace of the innovation cycle, which in the past was primarily glazing-driven. This is especially true for wooden frames. Today's most advanced labels for energy-efficient buildings, such as the German passive energy house standard, actually call for significantly improved window frames, in order to allow for the window as a whole to meet the required U-value specification of 0.8 W/m²K. However, significant scope for innovation on the glazing side remains, and news from leading R&D laboratories currently report improvements on two basic techniques, viz. (a) the inclusion of one or several foils between the glasses and (b) vacuum glazing (e.g. Zimmermann and Bertschinger (Eds.), 2001).

Window glazing is not only predominant with regard to the technical performance of a window in terms of energy efficiency, but it is also an important cost factor in window manufacturing that is subject to significant dynamics. As shown in Figure 16, the share of the glazing cost is about one-quarter of the price paid by the end-user. Interestingly, despite the impressive technical progress made over the last thirty years in terms of thermal conductivity, the price of coated double glazing has actually decreased by more than a factor of two (real 2001 prices). This trend, derived from data obtained from leading Swiss glazing manufacturers, has been confirmed by two other glazing companies, cf. Jakob et al. (2002) for details. Triple (non-coated) glazing showed a similar dynamics between the 1970s and the mid-1980s. Note that the absolute price level of triple glazing is lower than that of double glazing, since only the latter is coated (implying a higher energy efficiency).

From 1985 to 2000, the price for complete double-glazed windows remained roughly constant at around 400 CHF/m² in nominal terms, and decreased by about 10% over the last 15 years in real terms.

Over the same period of time, improvements of various technical characteristics (e.g. energy-relevant characteristics such as the U-value, but also regarding painting and weather protection and the like) could be realised. In contrast, the price of triple-glazed windows increased (decreased) modestly in normal (real) terms over the period 1990–2001.

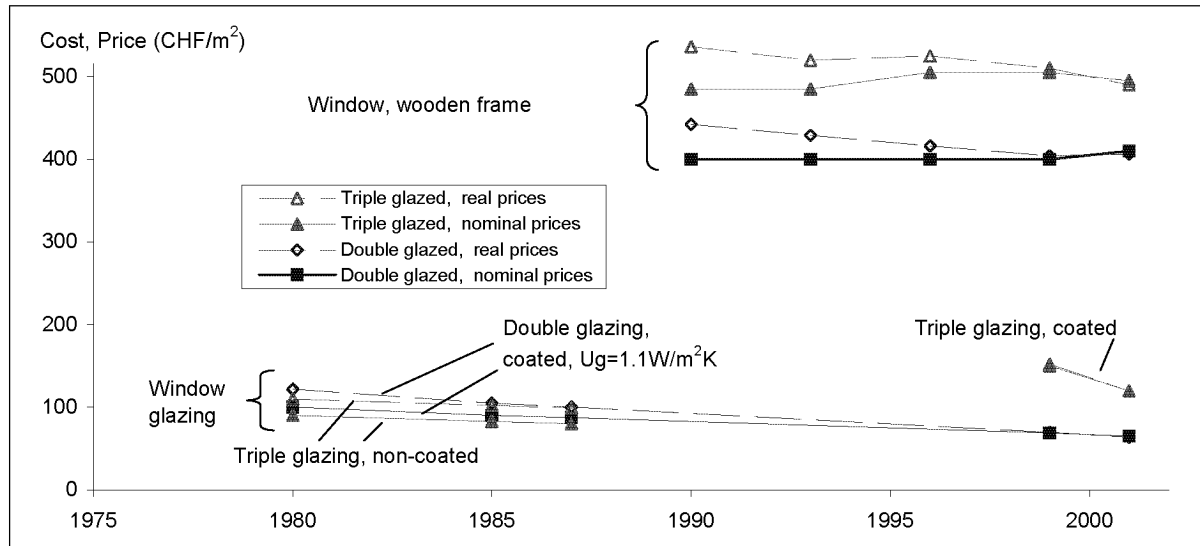


Figure 16 Cost dynamics for window glazing and for standard size wooden frame windows in Switzerland, 1980/1990–2001 (in real 2000 prices). Source: Adopted from Jakob et al. (2002), based on data from a Swiss glazing manufacturer and a major Swiss window manufacturer.

The findings depicted in Figure 16 are in accordance with those in Table 6, which contains the estimation by a window and façade manufacturing association’s representative regarding total cost and cost shares, respectively, of window production. The figures show that the costs of the glass used in window manufacturing have approximately halved from 1970 to 2000, while the (real) cost for material and coating and for assembly including transport has more or less remained constant, as has the contribution margin. Besides, the labour cost decreased substantially because of an increased output per employee ratio, which was enabled mainly by a transition to capital-intensive but highly efficient assembly lines. Overall, the cost of complete windows has decreased by some 25% over the last thirty years (in real 2000 prices; see Table 6).

Table 6 Cost of window manufacturing in 1970 and in 2000, nominal and real (U-value 1970 approx. 2.5–3.0 W/m²K; 2000 approx. 1.3 W/m²K), expressed in CHF/m² standard

	Glass	Material, coating	Window manufacturing	Assembly incl. transport	Calculated contribution margin	Total
1970						
- nominal	150	70	120	60	80	480
- real ¹⁾	202 ²⁾	94 ²⁾	135 ³⁾	80 ²⁾	90 ³⁾	601
2000						
	100	100	80	80	90	450

¹⁾ 2000 real prices
²⁾ adjusted with the Swiss producer price index for the manufacturing industry
³⁾ average price index for the construction of residential buildings

Source: Jakob et al. (2002), data obtained from an interview with a representative of SZFF (Schweizerische Zentralstelle für Fenster- und Fassadenbau), Dietikon/ZH.

Similar to other construction activities, the production and assembly of windows consists of cost components of different types. Ideally, deflation factors are chosen accordingly, but an appropriate deflation factor might not always be available for any cost type. In the present case, cost deflation factors of similar cost types were chosen.

The historical cumulative output must be known in order to perform experience curve calculations. Experts estimate that in Switzerland the annual volume of windows sold was roughly constant over the last three decades (apart from some short-term fluctuations) at a level of about 2.6–2.9 billion m² per year. Table 7 reports on estimations of historical market shares of windows of different energy quality (note that the time periods in the table are not equidistant). At least three very innovative glazing types were introduced, and the following interesting findings can be distilled:

- Innovative glazing technologies can reach high market penetration levels in a relatively short period of time, provided there is demand pull (e.g. created by legal requirements, labels): in Switzerland, for example, coated and inert-gas-filled double glazing gained a market share of almost 60% within only five years, although other improved window types (such as non-coated triple glazing) were already introduced in the market. The willingness and flexibility of the glazing manufacturers alleviated the transition process.
- The better is the enemy of the good: after coating and inert-gas-filling had been developed and brought to the marketing stage, the already ongoing diffusion of non-coated triple glazing (that was also innovative in comparison to non-coated double glazing) was stopped abruptly after 1985, mainly because it was technically inferior, aesthetically less attractive, and more expensive than the newer innovation.
- In the absence of an urgent (economic or legal) need or some special promotion campaign, the introduction of innovative technologies into the market is much slower than otherwise. Indeed, although (coated and inert-gas-filled) triple glazing was already available on the market in 1990 (2% market share), its market share has only risen to some 7% today. This is in stark contrast to the dynamics experienced for coated double glazing after the mid-1980s, which was encouraged by both general building codes (envelope as a whole – SIA 380/1) and specific building codes (construction elements – SIA 180).

Table 7 Development of the relative production output (quantity-based) for double and triple glazing in Switzerland, 1970–2001 (%)

Glazing category	1970 (%)	1980 (%)	1985 (%)	1990 (%)	1993 (%)	1996 (%)	1999 (%)	2001 (%)
Double glazing insulation	100	97	82	38	27	17	14	13
Double glazing insulation with heat protection coating	-	-	3	60	70	78	80	80
Triple glazing insulation	-	3	15	-	-	-	-	-
Triple glazing insulation with heat protection coating	-	-	-	2	3	5	6	7
Total production volume	100	100	100	100	100	100	100	100

Source: Jakob et al.(2002), based on data from a leading Swiss manufacturer of insulating glasses.

Experience curves and progress ratios for façades and windows

In what follows, we will briefly discuss the method that has been used to derive the progress ratios, pr , for efficiency measures applied to the building envelope. The useful energy conserved and

its specific costs are calculated against the reference case of a traditional wall construction with barely any energy efficiency insulation. The cost of conserved energy and thus the progress ratio depends on the U-value of the reference wall. To take into account uncertainty, two progress ratios are calculated, assuming a U-value for the reference wall of 1.0 W/m²K and 1.25 W/m²K, respectively. Hence the cost of energy conservation is calculated by subtracting non-energy relevant costs of façade application of between 35 CHF/m² and 40 CHF/m², arguing that these costs would have been necessary in any case (façade skin, connection to adjacent construction elements like windows). Each data point shown in Figure 17 represents half of a decade; the first data point stands for the 1975 situation and the last one for the year 2001.

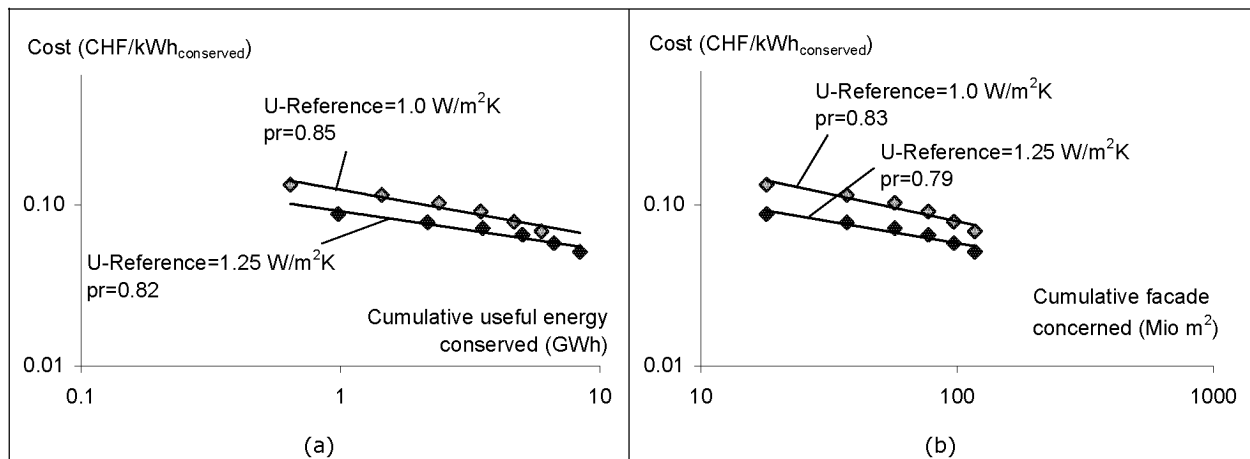


Figure 17 Experience curve estimation for façades, using different output categories: (a) cumulative useful energy conserved, (b) cumulative area of façades insulation applied (in logarithmic scales). Source: Own calculations

The progress ratios found vary between 0.79 and 0.83 for cumulative square metres of façade applied as a reference, and 0.82 to 0.85, respectively, for cumulative useful energy conserved as a reference (cf. Figure 17). Note that the progress ratio referring to the cumulative useful energy conserved turns out to be lower than the one referring to the cumulative area of façade applied. The reason is that due to different underlying measures of cumulative output, the progress ratios are not directly comparable³². Particularly, if the cumulative output measure is based on the cumulative energy conserved, then more doublings of output are required for the same reduction in cost of energy conserved, as compared to cumulative façade area used as a measure.

The progress ratios calculated for the time period 1985–2001 and for double-glazed coated windows are in the range of 0.83–0.88. The range reflects the uncertainty of the cost and the reference U-value at $t = t_0$.

³² Apart from the assumed reference U-value, further uncertainties to deal with concern the cost of the façade application (in CHF/m²) and the cumulative quantity applied. If the applied square metres for the first three periods were only about half as much as assumed in Figure 17, the resulting progress ratio would lie between 0.85 and 0.82 instead of 0.83 and 0.79.

3.4 Diffusion dynamics and optimal investment strategies

Experience curve analyses can be useful for energy efficiency policy design, policy-making and policy evaluation, although so far the major focus of the scientific community dealing with energy issues has been primarily on energy conversion technologies, and especially such based on renewable energy sources, see for example Isoard and Soria (2001), Menanteau (2000) or Neij, L. (1997). In what follows, we will first illustrate – with the help of a simple epidemic diffusion model (see e.g. Mahajan et al. (2000) for an overview) – how an accelerated market penetration of triple glazing may lead to a faster cost decrease (Section 3.4.1). Second, we discuss the optimal timing strategy for the insulation of new and existing building envelopes (Section 3.4.2).

3.4.1 Techno-economic dynamics in an accelerated market diffusion scenario

Figure 18 shows the resulting price trajectories for double and triple glazing different from the assumed market diffusion paths (measured in market share percentages). For the reference scenario, a standard Bass model formulation (Bass, 1969) has been fitted to the historical development of the market share for triple glazing (coated, inert-gas-filled, see Table 7) and the estimated diffusion curve (with coefficients $p = 0.1$, $q = 0.0035$) then extrapolated until 2030, leading to a relatively slow market share increase (from 7% in 2001 to 19% in 2010 to 42% in 2020). Applying a progress ratio of 0.9, this leads to a price decrease in real terms from 130 CHF/m² in 2001 to 104 CHF/m² (–20%) in 2010 and to 88 CHF/m² (–33%) in 2020.

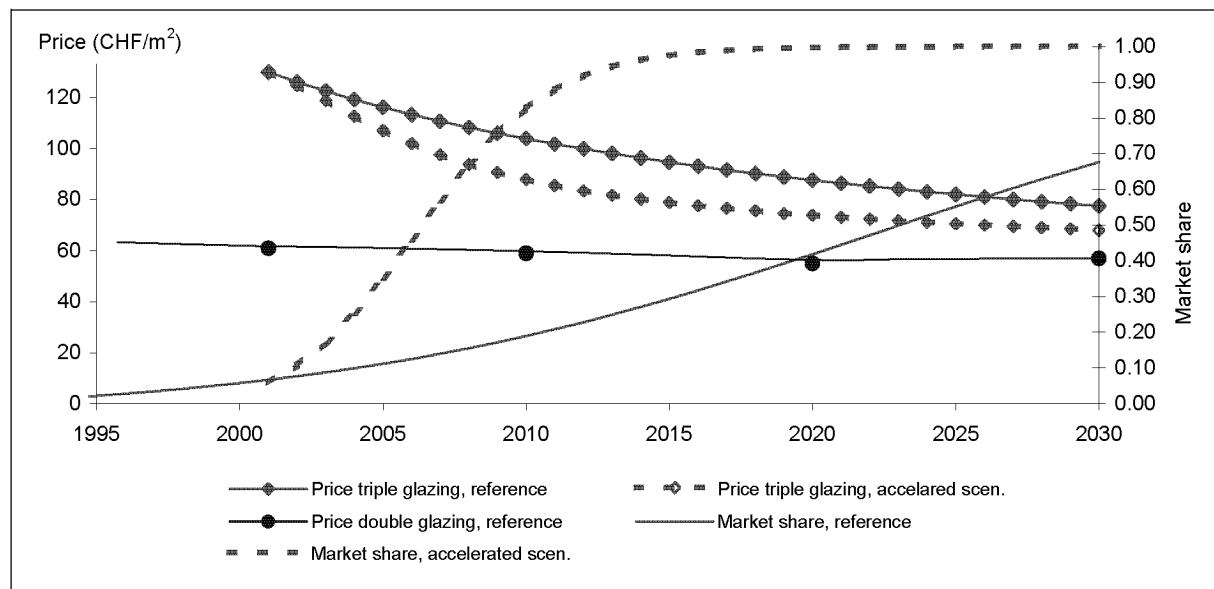


Figure 18 Price development paths for different assumptions on market shares for triple glazed windows, 1995–2030 (simulation). Source: Adopted from Jakob et al. (2002).

An accelerated introduction of triple glazing (dashed line), leading to more than 80% market share in 2010, would result in a more dynamic cost decrease (applying the same progress ratio): in 2010 the cost would drop to 68% of the 2001 price in 2010 and to 57% in 2020 (illustrative Figure 18). Thus the add-on cost and the marginal cost of energy efficiency (as compared to double glazing) would almost be halved in 2015. It is even imaginable that in the long run, the prices for double glazing rise again, as

the significance of mass production advantages fade. This was the case in Sweden, for example, where double-glazed windows were actually more expensive than triple-glazed ones.

3.4.2 *Optimal timing strategy for building envelope refurbishments within a dynamic techno-economic framework*

Even if prices of investments in energy efficiency measures (energy conservation measures) drop substantially in the future, this should not lead to the conclusion that the best strategy for investors is 'wait and see'. Particularly, the following cases can be distinguished:

- Choice of energy quality of the building envelope for new buildings and for energy-related building renewal: if 'only' today's average efficiency standards are applied, the building owner is exposed to the risk of energy price increases, especially compared to investments in appliances and end-use technologies that have a much shorter lifetime. Indeed, windows, and even more so façades, walls and floors have lifetimes of several decades and price increases during this kind of time horizons are quite probable (cf. Jochem and Jakob, 2002). Moreover, subsequent improvements of building envelopes that comply with current efficiency standards cause very high marginal energy conservation cost. Total façade costs including insulation are currently at around 120 CHF/m² for 12 cm insulation and 130 CHF/m² (best offer) to 170 CHF/m² (average price) for 25 cm to 30 cm, respectively. If 12 cm of insulation are applied today and a further 12 cm are applied in the future (and presuming that the energy prices are higher in 30 years' time than today), the total costs are roughly doubled (minus future cost decreases and minus some value added for the façade's renewal). Even if the future investment is discounted, the present value of the total cost is much higher. Furthermore, because of the high marginal costs of roughly 0.5–0.6 CHF/kWh (the second 12 cm have a much lower energy conservation effect, but the investment is almost as high as for the first 12 cm), no investor would invest into further improvement. The costs for the foregone option are thus quite high when investing today, but only at a rather low level.
- When deciding whether or not to add insulation to formerly non-insulated buildings, there is a second kind of lost opportunity. If a façade or a roof is renewed (coating, painting, tile replacement) and no insulation is added, at the same time an energy improvement opportunity is lost for typically 25–30 years (i.e. the time period after which façades are normally repaired and repainted) up to 40–50 years (time horizon for tile replacement). However, contrary to the case mentioned above, after this time there is a second chance to invest in energy improvements and the marginal cost of energy conservation will still be quite low. This is even true if the energy improvement is made before the end of the lifetime of the façade painting, because the investment opportunity (real option) forgone is only a prorated fraction of 30 CHF/m² to 40 CHF/m². This might be another reason why many of the building owners prefer to just maintain the building and to wait with more capital-intensive investments in energy efficiency improvements. It is needless to say, however, that there might be many other reasons for such a wait-and-see behaviour.

3.4.3 Marginal cost comparisons and sensitivity analysis with regard to experience curve effects

The marginal cost of energy efficiency measures aimed at the building envelope (e.g. improved wall insulation, energy-efficient windows) is proportional to the (annualised) cost difference between adopting a traditional and an innovative (i.e. improved) measure. However, for the latter the cost reduction potential through experience and learning effects is often greater, and it is likely that the cost reductions or technical improvements take place in a more dynamic way. Indeed, empirical evidence suggests that the time to double cumulative output is shorter and the progress ratios of new technologies are usually lower (i.e. the learning rate is higher) than for traditional technologies. As a consequence of pure arithmetic, it can be shown that the marginal costs decrease even faster: Let us suppose that the additional investment costs of improved insulation or windows are 30% higher and that the corresponding gross marginal costs of energy efficiency are 0.1 CHF/kWh. Then, it follows that if the costs of some improved measures drop by 15% over the same time period as the reference measure's costs decline by 10%, the cost difference between the two (and hence the marginal cost of energy efficiency measures) decreases by 32% down to some 0.07 CHF/kWh.

This phenomenon is valid for all marginal cost types where marginal costs of conserved energy are calculated as a difference of a reference investment and an improved or add-on energy efficiency measure, and where the latter have a higher and more dynamic cost reduction potential through learning and experience effects. In particular, the marginal costs of conserved energy of enhanced building envelope insulation including improved windows confirm the existence of this *narrowing gap phenomenon*. At the same time, the marginal costs of conserved energy by wall insulation, as compared to wall painting, behave less dynamically, i.e. only like the cost development of the reference insulation (in the example used –10% per time period) or – if improved insulation is being applied – like the dynamics of improved insulation (–15% per time period).

These considerations help to understand why the marginal costs of energy efficiency (i.e. heat energy demand reduction) measures have a significantly different dynamic behaviour, depending on the type of measure assessed (cf. Figure 19). Marginal costs of energy efficiency measures that have an add-on character (e.g. increase of insulation thickness, above-standard windows) typically evolve much more dynamically than marginal costs that arise from discrete and lumpy investment decisions (such as the yes/no installation of an air renewal system).

Finally, the adoption of energy efficiency measures applied to the building envelope could be fostered by communicating the achievable reduction in the heating system size and the achievable fuel cost savings to both building owners and tenants, and by explicitly accounting for the additional *net ancillary or co-benefits* created on top of the energy savings³³ – such as increased comfort of living, protection from external noise, improved net present value of the real property, or lower health damages due to a lowered energy demand for heating and related pollutant emissions. It has been shown that such additional benefits can be of a similar magnitude as the investment costs involved, and hence have a tremendous potential influence on the decision process, provided the additional benefits are actually known and can be reaped (see Jakob et al., 2002).

³³ Ancillary benefits indicate (usually monetised) effects that arise incidentally to certain policies, while co-benefits signal (usually monetised) effects that are explicitly taken into account as part of a particular policy. See for example Jochem and Madlener (2004); IPCC (2001); OECD (2000).

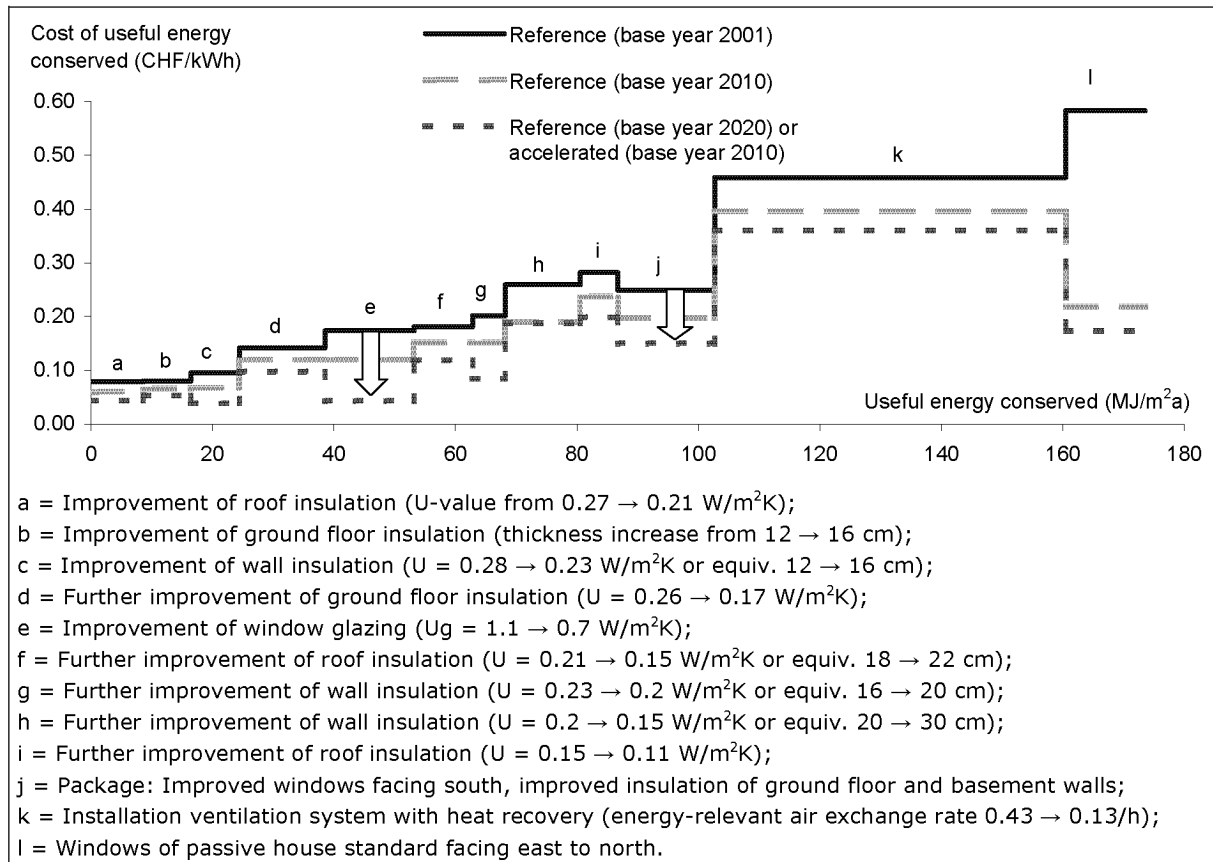


Figure 19 Marginal costs of energy efficiency measures/technologies in relation to the achievable energy efficiency gains for the construction of a new ordinary oil-heated multi-family house in Switzerland, current cost and future or accelerated ('enforced') price paths. Notes: Reference energy demand for space heating: $220 \text{ MJ/m}^2\text{a}$. Ratio of building envelope area to total floor area = 1.4. The arrows denote that the merit order of efficiency measures may change over time due to techno-economic progress. Source: Based on Jakob et al. (2002).

3.5 Conclusions and policy recommendations

In this paper, we have discussed various aspects of experience curve analysis of energy efficiency measures for the building envelope and pointed out potential merits for energy policy-makers. In particular, by using research results from an extensive recent study for Switzerland, we have illustrated important issues and complexities to be considered, without which the future cost efficiency of measures may be underestimated.

We demonstrate that experience curve analyses are also feasible in the area of energy efficiency measures in general, and such that are applied to reduce the energy demand of buildings. However, some caveats arise mainly from the fact that the cost of energy efficiency not only depends on the material and labour cost of the measure alone, but also on the energy efficiency level that is actually chosen. Furthermore, the long transition periods in case of structural change render the tracing of cost over cumulative output and thus the computation of experience curves a non-trivial issue. Some conceptual approaches have been shown to meet these challenges.

The analysis of some historical trends for Switzerland over the last thirty years has revealed some marked techno-economic progress that has been driven mainly by: (a) the establishment of building codes and standards; (b) energy price signals; (c) environmental concerns; (d) the active promotion of

labels and standards; and – as a consequence – (e) experience curve phenomena. Starting from the early 1980s and in line with technological progress, public authorities in cooperation with private associations have pushed building standards that were gradually adopted by policy-makers and eventually incorporated into jurisdiction as legally binding standards in an inter-cantonal diffusion process. In this respect, fiscal incentives played a minor role compared to command-and-control measures. Expected future trends important for improving the energy-efficiency of building envelopes comprise the promotion of labels (e.g. MINERGIE), GHG mitigation targets (e.g. as stipulated in the Swiss CO₂ Act) and related policy measures (e.g. imposition of a CO₂ levy), and other relevant policies (export, innovation, social, environmental, etc.).

For the time period 1975–2001, we find progress ratios for wall insulation of between 0.8 and 0.85 and for double-glazed coated windows, for the period 1985–2001, in the range of 0.83–0.88. Our empirical analysis yields technical progress factors of around 3% per annum for wall insulation and 3.3% p.a. for windows, respectively, based on Swiss data that cover the past 30 years. We find average real price decreases of 0.6% since 1985 for façades, and 25% over the last 30 years for windows.

From the preliminary experience curve analyses undertaken so far, we can derive the following tentative policy design recommendations:

- The imposition, effective control, and periodic revision of building standards help to ratchet down energy requirements of buildings and to foster the standardisation of building components, which itself can promote economies of scale and mass production and learning effects that accelerate the diffusion of energy efficiency measures related to the building envelope.
- Voluntary standards (e.g. MINERGIE, Passivenergiehaus) can spur innovation and learning, and significantly promote the standardisation of components and processes, and thus apart from economies of scale and mass production also lead to experience curve gains.
- Apart from the fuel cost savings that can be achieved by the energy efficiency measures discussed, it is important that decision-makers take net co- and ancillary benefits explicitly into account, as these can be in the same order as the investment costs and thus greatly influence the decision process in favour of energy efficiency improvements. Through a (temporarily limited) public support of the niche market of MINERGIE buildings, i.e. to support the observed willingness to pay for these co-benefits, learning investments can be financed which helps to bring down the costs of energy efficiency measures. Due to the narrowing gap phenomenon, the cost of energy efficiency decrease even more dynamically than the cost reduction of the measures themselves.

Overall, the promotion of the virtuous cycle ‘*standard → innovation → diffusion → cost reductions*’, the expected spillovers from building performance standards for new buildings to refurbishments of existing building envelopes, and the explicit accounting for net additional benefits are good starting points for successful and innovative energy efficiency policies that keep an eye on experience curve developments and hence also on the economically optimal timing for building envelope refurbishments.

CHAPTER 4

WILLINGNESS TO PAY FOR ENERGY-SAVING MEASURES IN RESIDENTIAL BUILDINGS (*BANFI ET AL., 2006*)

This Chapter 4 is being published in *Energy Economics* xx (2006) xxx–xxx (accepted 8 June 2006, available online) and is referred to as Jakob (2007).

Abstract

This paper uses a choice experiment to evaluate the consumers' willingness to pay for energy-saving measures in Switzerland's residential buildings. These measures include air renewal (ventilation) systems and insulation of windows and facades. Two groups of respondents consisting respectively of 163 apartment tenants and 142 house owners were asked to choose between their housing status quo and each one of the several hypothetical situations with different attributes and prices. The estimation method is based on a fixed-effects logit model. The results suggest that the benefits of the energy-saving attributes are significantly valued by the consumers. These benefits include both individual energy savings and environmental benefits as well as comfort benefits namely, thermal comfort, air quality and noise protection.

4.1 Introduction

As is the case in most industrialized countries in temperate zones, residential buildings in Switzerland incur an important share of the end use energy consumption. Thus, improvements of energy efficiency in the building sector could have an important impact on the country's total energy consumption and a considerable contribution in attaining the CO₂-emissions objectives for a sustainable development. The overall energy efficiency of a building is identified mainly by the insulation characteristics of the building envelope and the presence of an air renewal system.³⁴ Provided with an energy-efficient implementation, these measures yield two kinds of benefits: First, they reduce the energy consumption of the buildings hence costs, and secondly they generate comfort benefits namely, improved indoor air quality, thermal comfort and enhanced protection against external noise.

With a relatively long cycle of energy-relevant renovations in buildings (usually about 20 to 40 years), the Swiss building sector has still a very low usage of energy saving measures. Every year only one to two percent of the existing building envelopes undergo maintenance or renovation. In only 30 to

³⁴ Air renewal or ventilation systems have a controlled air exchange and provide the indoor spaces with fresh and filtered air (pre-heated by a heat-exchanger) without great heat losses through windows or traditional aeration systems. Not to confuse these systems, also known as "housing ventilation" or "comfort ventilation", with conventional air conditioning used for cooling or moisturizing.

50 percent of these cases the renovation measures include insulation with a reduction of the energy consumption by 50% to 70% and only a very small fraction opt for enhanced energy-efficiency measures that exploit the energy saving potential completely (see Jakob and Jochem, 2003). Houses with the latter measures satisfy the conditions set by *Minergie* label³⁵ reducing energy consumption by 70% to 85% for old buildings (constructed prior to the 1970s) or by 50% for today's new buildings.

The Swiss federal and cantonal governments support the renovation or new investments in houses satisfying the *Minergie* requirements through subsidies and/or reduced interest rates. Yet a relatively small number of houses are constructed (5 to 10 percent of new single family houses and less than 5% of new apartment buildings) and hardly any are renovated according to *Minergie* guidelines.

In a recent study, Ott et al (2005) have identified legal and social factors as well as market structural barriers and lack of consciousness as the possible explanations of low usage of energy-saving systems for the case of the Swiss residential building sector. Moreover, as shown by Jakob (2006), depending on the adopted assumptions and especially for ventilation systems, the discounted value of long-term savings in energy costs could be insufficient to justify such investments.

In order to identify effective policy measures to induce more investment in buildings' energy efficiency, it is important to have detailed information on the factors that influence the homeowners' investment decision and on their willingness to pay for the resulting improvements. Similarly in rental buildings it is important to know how consumers value apartments in energy-efficient buildings. However, there are only a few studies that addressed the consumer's valuation of energy-saving measures in buildings. One of the first studies is Cameron (1985) that analyzed the demand for energy-efficiency retrofits such as insulation and storm windows using the actual data collected by a national survey on energy consumption. Using a nested logit model that study shows a considerable sensitivity of demand to changes in investment costs, energy prices and income. In more recent literature, conjoint analysis was used in order to elicit the choice behavior of households for energy-saving measures. For instance, Poortinga et al. (2003) have focused on the characteristics of 23 energy-savings measures including insulation and energy-efficient heating systems in the Netherlands. The conjoint analysis was judged to be a useful method to examine the acceptability of these measures and identify the characteristics influencing the choices. A choice experiment was also carried out in Canada aiming at understanding the preferences of residential consumers when making investment decisions regarding heating system or a renovation that impacts the efficiency of home energy consumption (Sadler, 2003). The renovation choice was estimated using a binomial logit model and the heating system choice using a multinomial logit model. The results of that study suggest a high preference for the energy efficient renovations and highlight the effect of comfort in addition to the capital costs, the annual heating expenses and the subsidy regime.

This paper adopts a choice-experiment approach to analyze the willingness to pay (WTP) for energy-saving measures in residential buildings. The results provide the first WTP estimates based on choice experiments in the context of the Swiss housing sector. The analysis includes both renovation cases and new buildings. The decisions are related to purchasing single family houses as well as renting apartments. The estimation methodology is based on a binomial logit model with individual

³⁵ *Minergie* is a quality label that combines high comfort of living and low energy consumption with a limited cost surplus of at most 10% of the construction price. Controlled air exchange requirement, is mostly met with a ventilation system. More information is available at www.minergie.com.

fixed effects. The results suggest that energy-saving measures are significantly valued by the consumers, which in some cases can counter the implementation and operation costs.

The rest of the paper is organized as follows: Section 2 describes the experiment design; Section 3 presents the theoretical framework and the econometric methodology. A description of the data and the regression sample is provided in section 4. The estimation results are presented in section 5. A summary of the main results and the conclusions are given in section 6.

4.2 Experiment design

The data needed for the econometric estimation of the choice behavior can basically be collected with two different methods: the revealed and the stated preference method. The first method is based on the observation of the actual choice decisions of households from a set of alternatives that are known to the econometrician whereas the second method is based on information extracted from interviews or choice experiments. Verhoef and Franses (2002) and Louviere et al. (2000) provide overviews of the advantages and drawbacks of the two methods.

The aim of this study is to estimate the marginal willingness to pay (WTP) for different energy-saving characteristics. In principle, both revealed and stated preference methods could be used for this purpose. However, the small share of buildings with enhanced energy efficiency standards makes the use of a revealed preference method difficult.³⁶ Moreover, it is generally difficult to obtain data on the available choice set from which the alternative has been chosen. For the above reasons we use a stated preference method with choice experiment, initially developed by Louviere and Hensher (1982). This approach has been used in other energy-related topics, for example in Bergmann et al. (2006).

Two samples of households respectively consisting of residents of single family houses and rental apartments have been presented with several choice sets and asked to choose the alternative they prefer the most. In our case, respondents were asked to choose between their actual situation and a hypothetical housing with different energy efficiency attributes and a different price, with all other characteristics remaining the same. The price is defined as the purchase price for houses and the monthly rent for apartments. The following attributes are included in the experiment: windows with different energy efficiency standards; façade with different levels of insulation and esthetics; presence of a ventilation system; and price. These attributes and the related categories are listed in Table 8.

The respondents were asked to imagine that their actual housing situation would be improved (downgraded) in terms of the mentioned attributes, with all other characteristics such as number and size of rooms, location etc. being constant. The respondents' actual housing situation was chosen as a reference to reduce the hypothetical character of the survey (as compared to two hypothetical situations to choose from). The respondents already living in housing situations with a high energy efficiency standard were asked to imagine a decline in one or several of these features.³⁷ The price levels were related to the actual residence of the respondents and were chosen within a reasonable range. Each respondent was asked to do several choice tasks.

³⁶ The valuation of different housing attributes can be estimated by applying the hedonic pricing approach to market data.

³⁷ To make the choice tasks as realistic as possible, the set of categories of the hypothetical housing situations was adapted to the present situation of respondents. For respondents living in new buildings only category 1 and 2 of both window and façade were included in the choice set.

Each choice task consisted of reading a card listing the characteristics of the actual situation and those of one alternative and choosing the one of the two that was preferred. The respondents were provided with descriptive information about the attributes, in particular the relatively new and not widely installed housing ventilation system. This description included information about the characteristics of the attributes and about their positive impacts on the energy efficiency of the building and the comfort benefits such as thermal comfort, air quality and noise protection, see Ott et al. (2006) for more details. The respondents were also informed of the energy cost-savings as well as the entailed environmental improvements. However, we have not provided quantitative information about the extent of these benefits particularly on the potential cost savings at the individual level. In fact, in most real cases when buying or renting a residence, individuals do not have such quantitative information. Moreover, these benefits particularly the savings in energy costs vary across offered alternatives and strongly depend on the actual situation, hence many unobserved factors which were difficult to assess. It is assumed that the respondents assess the trade-off between prices and the overall benefits from different housing attributes. Thus, the willingness to pay estimates include comfort benefits and cost-savings as well as the respondents' potential valuation for environmental benefits.

To reflect the real-world choice situations (and to prevent strategic behavior) each of hypothetical alternative consisted of an upgrade in some attributes and/or a downgrade in some other attributes. This design was chosen to enrich the structure of the sample and was based on the assumption the respondents could answer differently depending on their personal experience about different energy efficiency attributes. In particular, we intentionally included respondents living in situations equipped with ventilation.³⁸

Table 8 Categories of different attributes (within attributes in descending order) and price levels considered in the choice experiment

Attribute	Categories
Window	<ol style="list-style-type: none"> 1. Enhanced insulation (triple glazing, double coated pane, rubber seal) ^{*)} 2. Standard insulation (coated, rubber seal) 3. Medium old (low insulation, not coated, no rubber seal) ^{**))} 4. Very old (single glazing, not coated, no rubber seal) ^{**))}
Facade	<ol style="list-style-type: none"> 1. Enhanced insulation ^{*)} 2. Standard insulation 3. No insulation, but newly repainted ^{**))} 4. Old (not repainted) ^{**))}
Ventilation	<ol style="list-style-type: none"> 1. With air renewal system (housing ventilation) 2. Without air renewal system
Price	In 5 levels: approximately -100, -50, 0, 50 and 100 CHF per month for rented apartments and -90'000, -45'000, 0 +45'000, +90'000 CHF per house, in addition to the actual price

^{*)} Applied only to new buildings

^{**))} Applied only to existing buildings

³⁸ Further details of the experiment are documented in Ott, Baur and Jakob (2006).

4.3 Model specification

With reference to the utility theory, the paper models the choice of respondents (apartment tenants, house buyers) for energy relevant characteristics of apartments and houses respectively. The underlying assumption is that households evaluate the characteristics of different housing alternatives and then choose the one which leads to the highest utility.³⁹ We assume that the utility of living in energy efficient apartments or houses is a function of the price, the housing's energy efficiency characteristics (for instance the characteristics of windows and façade and the presence of a ventilation system), the building location, household characteristics, and a random component that captures the influence of unobserved factors. The household characteristics can include income, education, environmental consciousness, as well as site-specific characteristics of the household's actual residence. Indeed, according to the random utility theory, the utility of goods or services is considered to depend on observable (deterministic) components, including a vector of attributes (X) and individual characteristics (Z), and a stochastic element e (cf. Louviere et al., 2000). Thus, the utility function of a bundle of characteristics i for individual q at choice task j can be represented as:

$$U_{qij} = V(X_{qij}, Z_q) + e_{qij} \quad (10)$$

where V is the deterministic part and e_{qij} the stochastic element. The deterministic variables that will be used in an empirical model are the housing attributes (X_{qij}) and the respondent's characteristics (Z_q). Assuming an extreme value distribution for the stochastic term e_{qij} in model (10), the probability of choosing alternative i out of a set of available alternatives $A=\{1, 2, \dots, K\}$ can be written in a logistic form as:

$$P_{qij} = \exp(V_{qij}) / \sum_{k=1}^K \exp(V_{qkj}) \quad (11)$$

Expression (11) is the basic equation of a multinomial logit (cf. Greene, 2003 and Thomas, 2000). Utility function V is generally assumed to be linear in parameters. In our case, the number of alternatives in each choice task is limited to two possibilities. Thus, the choice set for a given choice task j can be written as $A=\{0, j\}$ with 0 indicating the status quo and j representing the offered alternative. The random utilities of the resulting binary logit model can be written as:

$$U_{qj} = \beta X_{qj} + \alpha Z_q + e_{qj} ; U_{q0} = 0 \quad (12)$$

where Z_q represent the household characteristics that do not vary across choice tasks, and X_{qj} is the characteristics of the alternative situation of choice task j for individual q . α and β are the vectors of model parameters. In a multinomial logit framework, the parameters associated with one of the outcomes are normalized to zero namely, $U_{q0}=0$. Therefore, U_{qj} is the random utility of choosing the alternative situation over the status quo.

If all the relevant respondent's characteristics (Z_q) are observed, the model given in equation (12) is a simple binomial logit. In general however, Z_q can include a host of parameters, many of which are not observed. In this case, this term can be considered as an individual fixed effect. The resulting model is a fixed effect binary logit model proposed by Chamberlain (1980) and can be written as:

³⁹ In other words it is assumed that households maximize their utility function of hedonic commodities that they produce from the housing services and goods (Thompson, 2002).

$$U_{qj} = \beta X_{qj} + u_q + e_{qj} \quad \text{with } u_q = \alpha Z_q \quad (13)$$

It should be noted that because of the presence of fixed effects in the model, vector X_{qj} can be equivalently replaced by the $X_{qj} - X_{q0}$, which measures the difference between the characteristics of the hypothetical alternative with the status quo. This implies that U_{qj} measures the net gained value through moving from actual situation (status quo) to a hypothetical status offered in choice task j . Given that the hypothetical alternatives may equally involve a better or worse situation regarding comfort, the individual specific term u_q can be interpreted as the (dis)utility of respondent q from changing their status quo.

Assuming a logistic distribution for the error term, the above model can be estimated by maximization of the conditional likelihood given the fixed effects (u_q).⁴⁰ Chamberlain shows that for a consistent estimation, incidental parameters u_q should be replaced by a minimum sufficient statistic namely, the number of positive responses for a given individual. If we denote the individual q 's response for J choice tasks by the sequence $(y_{q1}, y_{q2}, \dots, y_{qJ})$, where $y_{qj} = 1$ if offer j is chosen, and $y_{qj} = 0$ if offer j is not chosen, then the number of positive responses (accepted offers) for individual q is obtained by the sum $s_q = \sum_{j=1}^J y_{qj}$. The conditional probability can therefore be written as:

$$\Pr(y_{q1}, y_{q2}, \dots, y_{qJ} | u_q) = \frac{\exp\left(\sum_{j=1}^J y_{qj} X_{qj} \beta\right)}{\sum_{d_{qj} \in \Omega} \exp\left(\sum_{j=1}^J d_{qj} X_{qj} \beta\right)} \quad (14)$$

where Ω is the set of all the sequences $(d_{q1}, d_{q2}, \dots, d_{qJ})$ in which the number of positive responses is equal to that of the chosen sequence namely, $\sum_{j=1}^J d_{qj} = \sum_{j=1}^J y_{qj} \equiv s_q$. Hence, the numerator represents the odds of choosing the sequence $(y_{q1}, y_{q2}, \dots, y_{qJ})$ and the denominator indicates the sum of the probabilities of all possible outcomes that entail the same number of accepted offers.

The fixed effect logit model is estimated using the maximum likelihood estimation method. Once the model parameters are estimated, the marginal rate of substitution between different attributes can be calculated. If one of the attributes is a numéraire or a monetary variable like price (p) the marginal willingness to pay for attribute x can be derived as:

$$WTP = - \frac{\frac{\partial V}{\partial x}}{\frac{\partial V}{\partial p}} \quad (15),$$

which is equivalent to the ratio of the corresponding coefficients in equation (12).

⁴⁰ See Hsiao (1986) and Greene (2003) for more details about the fixed-effects logit model and Ferrer-i-Carbonell (2004) for an application.

4.4 Data description

The data used in this paper were collected during Summer 2003 by telephone interviews in five cantons covering a major part of German-speaking Switzerland. The experiments have been performed on two separate samples for apartment buildings and single-family houses respectively. The first sample consists of tenants of rental flats whereas the second sample includes home-owners. Both samples have been selected from the households who have recently moved, thus have faced a housing choice decision within a few months before the experiment. The samples were stratified with the purpose of including a sufficient share of new and existing buildings, of standard and energy-efficient ones, of buildings with and without ventilation receptively.⁴¹ Both samples cover an important share of the German speaking part of Switzerland. The data sources from which respondents were randomly chosen were different for each stratum of the sample. These data sources include the list of labeled energy efficient houses published by the *Minergie* association (see footnote 35), a data base of a supplier of internet housing ads, and a database of another survey on buildings (Jakob and Jochem, 2003). Respondents' names and phone numbers were matched to the buildings' address using the public phone directory.

The telephone interviews have been conducted in two stages. In the first stage the respondents were recruited and basic information were collected to match the respondents to the different sample strata and to obtain information about their actual housing situation. The respondents were then provided with written information and the choice tasks. In the second stage, the choices and additional socio-economic information were collected by phone.

The first stage included 397 interviews for the rented flats and 402 interviews for single family houses, corresponding to a response rate of 36% and 41% respectively. The response rate of the second stage was 66% for the rented flats and 63% for the single family houses, resulting in overall response rates of 24% and 26% respectively. The response rate of the second stage is quite high and non-responses are mainly due to unavailability of some of the respondents. Thus the selection bias at this stage is relatively low. However, there could be a self-selection bias at the first stage of the survey. Persons interested in the subject (of energy efficiency and housing comfort) could be more likely to participate in the choice experiment. With the available data we cannot identify the extent of potential selection biases due to unobserved differences between the participants and the Swiss population. Compared to the average values of the Swiss population the studied samples show a slight over-representation of high-income and a considerable over-representation of educated individuals (Ott, Bauer and Jakob, 2006). Assuming that relatively educated individuals have a higher than average valuation of comfort and energy-efficiency, such sample selection biases might result in an overestimation of WTP.

The resulting samples obtained from the survey include 264 tenants of apartment buildings and 253 single family house owners with a total of 3861 and 3458 observations (choice tasks) respectively. After excluding the choice tasks with dominated alternatives and also the respondents that have consistently preferred their status quo over all the offered alternatives⁴², the final regression samples consist of 163 tenants with 1928 observations and 142 house purchasers with 1685 observations.

⁴¹ In the original study (Ott, Baur and Jakob 2006) the buildings constructed after 1995 and those with energy-efficiency labels have been distinguished from other buildings.

⁴² The respondents that have not shown any variation in their choices cannot be included in a fixed effects logit model.

The considerable rate of respondents always preferring their actual situation (101 out of 264 and 111 out of 253 respondents) may suggest that focusing on the remaining sample may create selection bias in the estimations. However, it should be noted that the experiment design is such that the alternative state does not necessarily have always higher attributes than the actual state. Therefore, the respondents who have never accepted any offer might rather have a relatively high disutility of change, or simply might have not examined all the offers. Therefore, to the extent that such disutilities are not correlated with the WTP, it is reasonable to assume that the WTP estimated from the regression sample are representative of the entire sample.

A descriptive summary of the sample used in the analysis is given in Table 9. The upper panel of the table lists the descriptive statistics of the respondents and the characteristics of their actual residence while the lower panel gives the attributes of the hypothetical alternatives offered in the experiment.

As seen in Table 9, the share of apartments with installed housing ventilation systems is about 14 percent of the sample and that of single family houses is about 9 percent. These shares are slightly lower than the corresponding ones of the entire samples (about 20 percent of 264 tenants and 17 percent of 253 single family houses). This difference suggests that the respondents living with a ventilation system are relatively less likely to give up their present situation regardless of the offered price discounts.

Regarding the energy efficiency attributes of the actual situation the sample can be described as follows: the most frequent type of windows is “Standard window” (67% of apartments, 80% of single-family houses) including coated glazing and sealing rubber. Only 13% of apartments and 9% of single-family houses (SFH) have enhanced windows (including coated triple glazing). 17% of the apartments and 9% of the SFHs have “old windows” (i.e. windows that were renovated before 1995 or not at all) including non coated double glazing and no sealing. A minor fraction of the buildings has still very old windows with only single glazing.

The two most frequent façade qualities in the samples are the standard insulation and the “old façade” (neither painted nor insulated the last few years) covering about one third each of them. More specifically, the shares of standard insulation are 34% (apartments) and 32% (SFH) and the “old façade” ones (nor painted or insulated the last few years) are 36% (apartments) and 31% (SFH).

In the final apartment sample, the number of valid observations (number of answered choice tasks per person) varies between 2 and 17 with an average of about 12 and a standard deviation of about 3.4⁴³. The number of accepted offers per person varies between 1 and 14 with an average of 3.4 accepted offers. The number of cards per person in the SFH sample varies between 7 and 18 with an average of about 14, from which 2.7 offers were accepted in average. The rental prices range between 430 and 4000 CHF/month and the standard deviation is 609 CHF/month. The purchase prices of the SFH range from CHF 100'000 to CHF 1.6 Million, with an average of CHF 659'000.

⁴³ For the econometric estimation, the choice situations with dominated alternatives and undecided choice tasks were excluded from the sample. In all the remaining choice tasks, the price of the hypothetical alternative is higher (lower) than that of the actual situation if and only if the alternative offer provides a strict improvement (decline) in at least one of the attributes while other attributes remain at least (most) the same as in the actual state.

Table 9 Descriptive statistics

Respondents and characteristics of their actual residence	Tenants		House buyers	
	Number of respondents	Sample Mean	Number of respondents	Sample Mean
Number of choice tasks per person	163	11.8 (3.4)	142	14.2 (2.6)
Number of accepted offers	163	3.40 (2.3)	142	2.68 (2.08)
Price of actual situation	163	1550 ^{r)} (609)	142	659 ^{p)} (230)
Enhanced window in actual situation	163	0.135	142	0.092
Standard insulated window in actual situation (*)	163	0.669	142	0.796
Medium old window in actual situation	163	0.166	142	0.085
Very old window in actual situation	163	0.030	142	0.028
Enhanced facade insulation in actual situation	163	0.190	142	0.204
Standard facade insulation in actual situation (**)	163	0.337	142	0.317
Repainted facade in actual situation	163	0.117	142	0.162
Old Facade in actual situation	163	0.356	142	0.317
Ventilation in actual situation	163	0.141	142	0.085
Old buildings (constructed before 1995)	163	0.650	142	0.549
<hr/>				
Hypothetical offers	Number of offers	Sample Mean	Number of offers	Sample Mean
Accepted offers (positive outcomes)	1928	0.288	1685	0.270
Price	1928	1509 ^{r)} (624)	1685	661 ^{p)} (242)
Enhanced window	1928	0.183	1685	0.188
Standard window (*)	1928	0.293	1685	0.256
Medium old window	1928	0.272	1685	0.292
Very old window	1928	0.252	1685	0.264
Enhanced facade	1928	0.172	1685	0.160
Standard facade insulation (**)	1928	0.401	1685	0.398
Repainted facade	1928	0.217	1685	0.216
Old facade	1928	0.210	1685	0.227
Ventilation	1928	0.661	1685	0.690
<hr/>				
All variables except prices are dummy variables. Standard deviations for prices are given in parentheses.				
(*) Reference Category for windows		(**) Reference category for facade		
^{r)} Monthly rent in Swiss Francs (CHF).		^{p)} Purchase prices in thousand Swiss Francs (CHF).		

A descriptive summary of the characteristics of the hypothetical offers is given in the lower panel of in Table 9. The sample of the choices can be described as a balanced sample in that there is a comparable share of old, standard and enhanced windows in the offered alternatives. This is also valid for the façade quality and the presence of a ventilation system. About 25% of the offers had very old windows. Rental prices of offers vary between 323 and 4600 CHF/month, with an average of 1509 CHF/month. In both samples the average price of offers is about the same as the average price of the

actual situation, which is due to similar number of price increases and decreases. Despite the fact that the offers are balanced, only less than one third of the offers were accepted (29% in the apartment sample and 19% in the SFH sample). This result might suggest a significant disutility of change.

The explanatory variables include the price (monthly rent for apartments and purchase price for single family houses)⁴⁴ and the energy efficiency attributes of the hypothetical offers. These attributes consist of three dummy variables for window attributes and three dummies for the facade characteristics with the standard (insulation) type being chosen as the omitted category in both cases and one dummy for ventilation system (see Table 8). An observation reported by Ott, Baur and Jakob (2006) is that the respondents who already have a given attribute in their households might attach a higher value to that attribute compared to other individuals. In order to control for potentially asymmetric choice behaviour,⁴⁵ a dummy variable has been constructed to indicate the hypothetical offers with lower-than-actual prices, which entail a decline at least in some of the attributes while others being unchanged. The interaction of this dummy with price is included in the model.

Because of the fixed effects included in the model, the household characteristics can only be included through interaction terms. In a preliminary analysis several interaction terms between alternative attributes and household characteristics have been considered. Using several hypotheses we explored if households with different characteristics and socio-economic variables differ with respect to their valuation of energy efficiency attributes. For instance, we tested if households with smoking habits or with pets have a different valuation of ventilation systems and/or people living in noisy locations have a higher valuation of insulated windows. The results suggested that all the interaction terms were statistically insignificant at 10% significance level.⁴⁶ We expected that household income might have an important effect. However, due to a relatively high share of missing values (about half of the sample) we could not include any income variable.

Therefore, in order to keep the model as parsimonious as possible and avoid unnecessary complication in the interpretation of the results, we decided to exclude such interaction terms from the model. The only exception is the different valuation of ventilation systems across new and old buildings. Our results suggest that the air renewal systems could be valued more in new buildings constructed after 1995 (less than 10-years-old). An interaction term is included in the model to account for such differences.

4.5 Results

The estimation results are shown in Table 10. The results regarding house purchasers and tenants show a very similar pattern. The coefficients of the price and of all energy-efficiency attributes have the expected sign and most of them are significantly different from zero at 5% significance level. Exceptions are the coefficients for enhanced windows and the interaction variable between ventilation

⁴⁴ Price variable is actually the difference between hypothetical and actual prices for each observation (choice task). Note that thanks to the fixed effects, it would not matter if the price levels of the hypothetical alternatives were used instead.

⁴⁵ This asymmetric behavior, commonly referred to as the disparity between the willingness to accept (WTA) and the WTP, is usually observed in similar experiments and widely discussed in the literature (Horowitz and McConnell, 2002 and Sayman and Öncüler, 2005). This disparity has been explained by several factors including those related to the survey design and framing effects as well as economic and psychological factors. In our experiment the asymmetry might be exacerbated by the fact that some of the high-level attributes are completely new to the respondents and might be valued less than those already experienced.

⁴⁶ The details of these analyses are not included in this paper.

system and new buildings for the rented flats. A significant difference in the price effects was found between price increases (price of the hypothetical alternative is higher than the price of the actual apartment) and price decreases.

Table 10 Estimation results of the logit model with individual fixed effects

Attributes	Rented flats in apartment buildings			Purchase of single family houses		
	Coeff.	Std. Err.	Sig.	Coeff.	Std. Err.	Sig.
Price ¹⁾	-0.0089	0.0009	***	-0.0229	0.0033	***
Price * dummy decreasing price	0.0047	0.0014	***	0.013	0.0055	**
Enhanced insulated window ²⁾	0.15	0.21	n.s.	0.14	0.23	n.s.
Enhanced facade insulation ³⁾	0.50	0.20	**	0.51	0.23	**
Housing ventilation system	0.90	0.17	***	0.54	0.21	***
Housing ventilation system * new building	0.46	0.32	n.s.	1.33	0.38	***
Medium old windows ²⁾	-1.49	0.22	***	-1.95	0.24	***
Very old windows	-2.68	0.25	***	-3.08	0.29	***
Painted facade ³⁾	-0.73	0.22	***	-0.97	0.25	***
Unpainted facade ³⁾	-1.10	0.22	***	-1.48	0.25	***
No. of persons	157			142		
No. of observations (choice tasks)	1928			1685		
Log likelihood	-540.44			-435.12		
Pseudo R ²	0.318			0.298		

¹⁾ Prices are expressed in CHF/month for rented flats and in thousand CHF for single family houses

²⁾ Reference category: new standard insulated windows ³⁾ reference category: standard insulated facade

Sig. = Significance level: *** 0.01, ** 0.05, * 0.1, n.s. = not significantly different from 0 at the 10% level

Using equations (12) and (15) we can calculate the willingness to pay for each attribute, which is the ratio of the attribute's coefficient and the price coefficient.⁴⁷ The WTP results in Table 11 are expressed as a percentage of the reference purchase price for houses, and as a percentage of the reference rental price for flats. The average prices of both new and old buildings are used as reference.⁴⁸ In new buildings the willingness to pay for enhanced façade insulation is about 3% whereas the ventilation system is valued with 4% to 12% of the reference price. In relative terms, house buyers and apartment tenants have a similar WTP for the case of new buildings. It is worth noting that the survey was conducted in Summer 2003 which was an extraordinary Summer with high temperature. This might explain the relatively high WTP for ventilation systems. Even though a comfort ventilation system as considered here is not designed for cooling, the respondents might have associated cooling with this system.

In the existing (not new) buildings we estimate the WTP for energy efficient façades and windows. Regarding the façade there is a WTP for insulation of 6% and 7% for SFH, whereas the estimated WTP

⁴⁷ The WTA could be calculated similarly accounting for the interaction of price and the decreasing-price dummy. The estimation results suggest that the WTA/WTP ratio is 2.1 in the case of rental flats and 2.3 in the case of single family houses. This is consistent with the results reported in the literature (cf. Sayman and Öncüler, 2005). In the paper we focus on the WTP that has more importance from a policy point of view.

⁴⁸ These prices are 650'000 and 686'000 CHF for new and existing single family houses respectively and 2030 and 1330 CHF/month for flats in new and in existing buildings respectively.

for esthetic reasons is low (about 3%) and only for single family houses significant at the 10% level. In existing buildings, the willingness to pay is particularly high for window improvements. Indeed, the WTP for a standard insulation window as compared to an old window is 13% for tenants as well as for house purchasers. Note that today's standard insulation windows are coated and have sealing rubber whereas old windows do not dispose of these properties. Coated windows have a higher surface temperature and sealing rubber protect from air infiltration and from external noise. Thus, such windows improve thermal comfort and comfort of living which might explain these relatively high WTP.

Comparing the results of windows and façades for old and new buildings shows that the marginal WTP for each further step of energy efficiency is decreasing. This result suggests that the "first" improvement provides a higher utility than that of an additional improvement.

Table 11 Marginal willingness to pay derived from discrete choice models, expressed as % of rental price (flats) and purchase price (single family houses) respectively ⁴⁸

Attribute	Rented flats in multi-family houses				Purchase of single family houses			
	WTP	Sig.	95%-Interval		WTP	Sig.	95%-Interval	
Enhanced insulated window (as compared to standard insulated windows)	1%	n.s.	-1%	3%	1%	n.s.	-2%	4%
Enhanced facade insulation (As compared to standard insulation)	3%	*	1%	5%	3%	**	0%	6%
Housing ventilation system (new buildings)	8%	***	4%	11%	12%	***	6%	17%
Housing ventilation system (existing buildings)	8%	***	4%	11%	4%	**	1%	7%
New windows (as compared to medium old ones)	13%	***	8%	17%	13%	***	9 %	18%
Medium old windows (as compared very old ones)	10%	***	6%	14%	8%	***	4%	11%
Standard facade insulation (as compared to facade painting)	6%	**	3%	10%	7%	***	3%	10%
Facade painting (as compared to old unpainted facade)	3%	n.s.	-1%	7%	3%	*	0%	7%

WTP = Willingness To Pay, expressed as % of rental price (flats) and purchase price (SFH) respectively
 Sig. = Significance level: *** 0.01, ** 0.05, * 0.1, n.s. = not significantly different from 0 at the 10% level

The WTP for ventilation systems in old buildings is below that of new buildings. This could be explained by different preferences of residents living in old and new buildings or by the different reference price level. The respondents who live in new buildings might have a relatively high standard of living, thus higher WTP for comfort. Note that in the case of tenants, the willingness to pay in relative terms, is very similar across old and new buildings. That the willingness to pay for ventilation is different between persons living in new and old buildings could be interpreted as an income effect, since income of people living in new buildings is slightly higher than those living in not new buildings. Finally, it should be noted that the WTP values include both the willingness to pay for improved comfort, for increased energy efficiency i.e. reduced energy costs and eventually for environmental improvements.

The willingness to pay for energy-efficiency attributes can be compared with the capital costs of implementing such attributes. In Jakob et al (2006) some typical capital costs are given for the example

of a typical flat of hundred square meters and for a typical single family house. For most of the considered attributes the monthly capital costs are significantly lower than the average willingness to pay of the sample as reported in Table 11.

That the willingness to pay exceeds the cost can be interpreted in different ways: On the one hand it could indicate that people actually desire enhanced efficiency but that the housing market has not yet reacted to this demand. On the other hand the values of the estimated willingness to pay could be overestimated.

The estimated values of WTP can be compared with the results obtained from hedonic pricing method (Ott et al, 2006). According to those results in the greater Zurich area the marginal value of Minergie label is about 7.5% of the rental price for new buildings and that of a renovated, insulated façade is about 8%. It is interesting to note that the estimated WTP values in this paper are comparable with these price effects obtained using data from revealed preferences through market prices.

4.6 Summary and Conclusion

This paper gives some insight into the willingness to pay for improvements in energy efficiency by studying stated choices of two samples of respondents respectively consisting of tenants of rental apartments and owners of single family houses. The considered energy saving measures include air renewal system and different energy efficiency standards of windows and façade. The data used for the econometric estimation were collected with a choice experiment. The respondents were presented with choice sets and asked to choose between their actual housing situation and a hypothetical one with different energy efficiency standards and a different price. The decision to use a stated preference method is supported by the fact that revealed preference data is only scarcely available since the market of energy efficient houses is still small. Further, this method made it possible to compare the willingness to pay of people who have already experienced the additional comfort benefits of energy-saving measures with those who don not have such information.

The econometric analysis of the data has been carried out using a fixed effect logit model. The coefficients of all attributes have the expected signs and most of them are significantly different from zero. The results show a significant willingness to pay (WTP) for energy efficiency attributes of rental apartments and of purchased houses. The willingness to pay varies between 3% of the price for an enhanced insulated façade (in comparison to a standard insulation) and 8% to 13% of the price for a ventilation system in new buildings or insulated windows in old buildings (compared to old windows) respectively. Note that the interrelation of the WTP values for different attributes are quite plausible and the results reflect a decreasing marginal utility for increasing energy efficiency.

The WTP values presented in this paper could be an overestimation of the representative values in the Swiss population, due to possible overrepresentation of respondents with high education and/or income and the relatively high participation rate of environmentally conscious individuals. Moreover, an overestimation could result from the hypothetical choice situation, relying on individuals stating their behavioral intentions rather than on revealed economic decisions.

The WTP is generally higher than the costs of implementing these attributes. Therefore it would be economically reasonable for owners and housing promoters to invest in energy saving measures. We assume that besides many legal, structural and socio-economic barriers the observed under-investment is due to lack of information regarding the advantages of the efficiency measures and perhaps lack of methods to quantify these advantages in economic terms. Indeed house owners,

architects, tenants and financial institutions have occasionally deplored this lack of economic foundation.

From a policy point of view, the government can reduce these barriers by supporting the communication and information for decision makers namely consumers, investors and financial institutions. A good example of this kind of promotion is given by advertising campaigns (so called "casa clima") used by the government of the Italian province Alto Adige, or by information campaigns and subsidies applied to energy efficient buildings in Switzerland, namely Minergie guidelines that combines efficiency and comfort. The authors recommend that the WTP results presented in this paper could be included in these promotion campaigns. In addition to an enhancement in communication, the governments could grant additional financial resources to the house owners who want to invest in energy efficiency measures to overcome financial barriers. Some Swiss financial institutions award credits with lower interest rates for Minergie labeled buildings. It should be considered that government intervention could speed up process the cost reduction (learning curve) of measures improving energy efficiency in buildings.

Nonetheless the WTP values presented in this study should be considered with caution. The results give a first estimate of the magnitude of benefits (willingness to pay) coming from energy-efficiency measures. Given the mostly lower costs of these measures, it may be possible by additional information of house owners, architects and tenants to increase significantly the share of energy efficient buildings.

CHAPTER 5

THE DRIVERS OF AND THE BARRIERS TO ENERGY EFFICIENCY IN RENOVATION DECISIONS OF SINGLE-FAMILY HOME-OWNERS (*JAKOB, 2007*)

This Chapter was published in March 2007 as CEPE-Working paper No. 56 and is referred to as Jakob (2007).

Abstract

Building renovation is one of the key factors in fostering energy efficiency in the building sector. However with regard to the long-term policy goals such as the Kyoto-Protocol and the IPCC recommendations the past and current rates of such renovations have been too low in most European countries including Switzerland. To identify the relevant factors affecting the renovation decisions of single family home owners three approaches are pursued. The first one consist of an analysis of the exogenous economic, technical and legal frameworks. In the second approach the perception of these boundary conditions by the owners from their subjective point of view is analysed, relying on a survey of owners of single-family homes. Owners were also queried about their motivations and reasons for insulating or not insulating. The third approach consists in the modelling of renovation decision regarding the building envelope based on revealed discrete choice data gained from a survey conducted in the Swiss residential building sector. The model is specified in relation to technical, socio-economic and behavioural hypotheses to test for commonly stated assumptions regarding drivers of and barriers to energy efficiency renovations. From the three approaches it can be concluded that building envelope renovations are affected by technical parameters, and general housing activities such as building extensions and motivations rather than by socio-economic variables such as income, education or age. Finally, findings are used to draw policy implications regarding instruments to promote energy efficiency in the buildings sector.

5.1 Introduction

The stock of existing buildings dominates the heating energy demand of the residential sector. In 2005 about two thirds of the heated floor area are in buildings constructed before 1980, i.e. before building insulation had a significant impact (based on data from Aebischer et al., 2002) and the share of these buildings in terms of heating energy demand is almost three quarters, mostly covered by fossil fuels. In view of this relevance and in view of the medium- and long-term energy and environmental policy goals and necessities (Kyoto-Protocol, CO₂-law, 2000 Watt-society, IPCC recommendations) it is indispensable to curb the energy demand of existing buildings, all the more so because energy efficiency (EE) potentials are larger than in new buildings, both on the individual and on the aggregate level.

A key factor of energy efficiency in the sector of the existing building stock is the renovation of the building envelope energy efficiency. For several reasons the building envelope is particularly relevant. Firstly, energy efficiency potentials are particularly large, amounting to about 50% or more if the envelope is renovated comprehensively. Secondly, it determines the level of useful energy requirements which is relevant for both fossil fuelled and renewable energy-based heating systems, since renewables are also scarce or need a scarce input energy (electricity in the case of heat pumps). Thirdly, an energy-efficient envelope facilitates efficient heating systems (particularly heat pumps) and last but not least it generates additional benefits such as improved housing comfort, which are also economically relevant (cf. Banfi et al., 2006). Finally, energy-efficient building envelopes are also a prerequisite for an extensive use of renewable energies whose potentials are limited (cf. Hirschberg et al., 2005, and others).

In Jakob (2006) it has been shown that energy-efficient building renovation is quite cost-effective or even economically viable, at least if regarded from a comprehensive lifecycle point of view which takes into account long-term considerations (e.g. time horizon close to technical lifetime, moderate interest rates, potential energy price risks) and all the more so if co-benefits are evaluated appropriately, cf. Banfi et al. (2006).

However, despite the high relevance of the issue and despite the relatively favourable economics, energy-efficient renovations were and still are only being undertaken at a relatively low rate, as it is shown by Jakob, Jochem (2003) and by Gerheuser (2007).⁴⁹ The rates of energy-efficient renovations were and are still quite low. In absolute terms, i.e. relative to the total of the building stock, the average EE renovation rates of the opaque envelope were between 0.4%/a and 0.8%/a during the 1990s and up to 2003. Exceptions are flat roofs and windows, whose rates were between 1.3%/a and 1.7%/a (cf. Jakob, 2006b). Although the rates are higher for some construction periods they are – being equivalent to renovation cycles of 50 to 100 years or more – clearly too low in view of the goals mentioned above.

Table 12 Annual renovation rates for single-family houses (SFH) and multi-family houses (MFH) for the different elements of the building envelope (average renovation rates 1990 to 2000, rates are referred to the building stock of the construction period up to 2000)

	Energy-efficient renovations		Overhauling	
	EFH	MFH	EFH	MFH
Window	1.3%	1.7%	0.1%	0.1%
External wall	0.4%	0.8%	1.3%	1.2%
Flat roof	1.3%	1.7%	0.1%	0.6%
External steep roof including attic floor	0.5%	0.8%	0.6%	0.9%
Ground floor, basement ceiling	0.6%	0.8%	0.0%	0.0%
Overall (area weighted average)	0.6%	1.0%	0.6%	0.6%

Source: Jakob (2006b)

The rates are also low in relative terms, i.e. relative to the total of building envelope measures being undertaken in a given period. For most of the building periods façade insulation were realised

⁴⁹ Note that the renovation rates surveyed by the ten-yearly conducted "Volkszählung" are not suitable as a measure of energy-efficiency renovations since it records "renovations that increased the value of the building", including both renovation of the building envelope and internal renovations.

only in 10% to 40% of those cases which involved any type of façade measures, the remainder including only overhauling (painting), cf. Jakob and Jochem (2003). Thus, the opportunity of cost-effective energy efficiency improvements was taken only in a minority of the cases.

Similar discrepancies between actual and expected behaviour were reported in other fields of energy use, and particularly in the field of energy efficiency, cf. Sorrel et al., (2004) and Jakob and Madlener (2003) for an overview. The question that arises at this stage is what the actual causes in the case of existing residential buildings in Switzerland are. To what extent is this observed discrepancy due to the different viewpoints between the private and the societal perspectives (time horizon, interest rates) and to which extent is it due to market failures or barriers? What are the legal, economic, and intrinsic drivers that stimulate energy-efficient renovations and which barriers and inadequate market mechanisms hinder a further diffusion of such renovations? Answers to these questions will be useful in defining a set of policy instruments to stimulate energy-efficient renovations and in taking advantage of the cost-effective potentials to mitigate climate change.

The renovation and overhauling behaviour of building owners is influenced by both exogenous and endogenous explanatory factors (see also the overview diagram on page 85 in Ott, Jakob et al., 2005). In this paper the analysis of the current renovation behaviour and of the relevant factors of influence on renovation activities is based on three approaches. The first consists of an analysis of the exogenous economic, technical and legal boundary conditions that impact on the renovation behaviour (section 5.2). In the second approach the perception of these conditions by the owners from their subjective point of view is analysed, relying on a survey of owners of single-family homes (section 5.3).⁵⁰ The third approach comprises the econometric modelling of the renovation decisions of (single-family house) owners based on a revealed preference approach (section 5.4), taking into account evidence gained from the previous sections. The modelling is based on data gained from two surveys (cf. Jakob, Jochem, 2003 and Ott, Jakob et al., 2005).

5.2 Technical, legal and economic framework conditions

In this section the technical, legal and economic framework are analysed regarding their impact on energy efficiency in the case of building renovations. The scope includes building and planning regulations, energy, climate policy and clean air regulations, tax law, renovation costs, financial needs, and economic viability considerations, local demand for housing and other general frame conditions (such as energy prices, mortgage interest rates and financing conditions). In each case it is analysed to what extent energy-efficient renovations are rather hindered or rather stimulated. After some short introductory remarks on the technical and physical condition of single-family houses in Switzerland and an analysis of the relevant technical and fiscal codes and regulations, the literature about the cost-effectiveness of building renovation is reviewed, and a discussion of the current market mechanisms and trends is provided. The analysis hereafter focuses on the building envelope which presents particularly large challenges. To a large extent, the insights can be transferred analogously to building services (such as heating and ventilation) if specific differences are taken into account.

⁵⁰ The first two sections are based on evidence (and methods used) gained in the context of two research projects about the renovation behaviour, potential barriers hindering a stronger diffusion of energy efficient renovations and potential policy measures to stimulate such renovations (Jakob, Jochem, 2003; Ott, Jakob et al., 2005). The latter reference is the research project "Mobilisation of energy efficiency potentials" co conducted on behalf of the Swiss Federal Offices of Energy (SFOE) and of Housing (BWO) whose financial support is gratefully acknowledged.

The first questions that was addressed was whether the general physical or technical conditions tend to induce or rather hinder energy efficiency renovations. It was found that in most cases building conditions neither hinder energy-efficient renovation nor urgently call for them. Indeed, from a technical or from a building physics point of view, energy-efficient renovations such as insulations or window replacement can basically be applied to all types of buildings and to most types of building elements. General architectural considerations may restrict renovations, but mostly only external façade insulations are concerned⁵¹. On the other hand most buildings can be operated and lived in with hardly any restrictions or problems for decades even without additional insulations. Hence, energy efficiency improvements are generally not triggered by technical factors: This would only be the case if residents became more demanding regarding indoor climate or environmental issues can a renovation need possibly be derived from the building's general condition. Exceptions are windows and flat roofs where energy efficiency is stimulated by technical factors. Indeed, new windows that replace existing ones are much more energy-efficient due to the considerable techno-economic progress of the standard market offers (cf. Jakob and Madlener, 2004). In the case of flat roofs it is the shorter technical lifetime (as compared to steep roofs) and construction damages that initiate EE improvements; if the roof membrane is renewed, thermal insulation is usually replaced or enforced and more advanced insulation is applied (cf. Jakob, Jochem et al., 2002).

5.2.1 Regulations

There are two kinds of regulations to be distinguished: firstly, general building and planning regulations which might pursue very different kinds of goals and could have an indirect, and unintentional effect on the energy efficiency of buildings and their renovations, and, secondly, specific codes and standards that are specifically designed to improve the energy efficiency of buildings. The analysis of codes and regulation of several cantons and communities reveals that neither is of great relevance (cf. Ott et al., 2005).

Indeed, the obstacles from the planning law are limited: deviations from surveying and zoning regulations generally tolerate post-insulation of walls and roofs as exceptions or explicitly permitted them, depending on the regional or municipal regulations. Slightly more relevant in practice are the conflicts of interest between the protection of listed buildings and conservation areas (preservation orders) and the demand for energy-related refurbishments, mainly in the core of small towns and cities. According to experts, roughly estimated at 10% to, at the most, 20% of the buildings are concerned and of these buildings not the whole envelope is affected, but mainly the façades. Finally legal restrictions due to neighbours' rights might hinder external insulation in some cases.

Further, a large part of the building stock is not at all or only sporadically affected by energy-related regulations. Indeed, there are no mandatory renovation requirements and the legal regulations only affect conversions, extensions and annexes in the building stock as well as – in some cantons – comprehensive modernisations, but not the existing building stock in general. Further, requirements for these renovation cases are technically and economically sub-optimal, at least from a long-term point of view (cf. Jakob, Jochem et al., 2002). From the perspectives of technological progress and economic efficiency, the legal requirements of thermal insulation are slack and should be tightened, both the performance based (SIA 380/1) and the building element based ones.

⁵¹ Note that renovation in many cases rather improves the architectural expression.

5.2.2 *Economic, financial and fiscal barriers and drivers*

Although other considerations might also impact on renovation decisions, economic determinants such as costs, financial needs, and the outcome of cost-benefit estimations certainly are very relevant. In this section the cost-effectiveness of EE renovations for private building owners is addressed. The effect of the current tax system is likewise demonstrated.

Financial needs and access to capital

As pointed out in Jakob, Jochem et al. (2002), energy efficiency renovations generally call for substantial additional up-front investments, as compared to repairing or overhauling options. The costs of façade overhauling for instance are typically 30 to 40 CHF/m² whereas the costs of façade insulations typically amount to 120 to 180 CHF/m² or even more, depending on the type of façade chosen. The additional costs of roof insulation are comparable; those for loft floor or basement ceiling slightly lower. The extra upfront costs of window replacement are also considerable if the state of the windows does not call for replacement or if repair and painting is possible (350 to 500 CHF/m², depending on the reference case).

Hence, as long as the condition of façades, roofs and windows allows repairing and painting, the additional up-front financial needs for energy efficiency improvements are considerable. In the case of single-family houses the total financial needs might amount to 40'000 to 70'000 CHF or more, depending on the geometrical size and proportions and on the share of building envelope that is renovated, which is 7% to 10% of typical purchase prices of existing SFH. For most single-family house-owners this is not a negligible amount, all the more since achievable energy cost savings are spread over a long time period (30 to 50 years). This need would have to be covered either by one's own savings, perhaps combined with raising the mortgage. In the first case renovations are in direct competition with other expenses (vacation, car) or needs (social security, health, living in the case of retired owners).

The economic viability of energy efficiency renovations from a private perspective

As opposed to the overhauling or doing-nothing option, the life cycle cost structure of energy efficiency renovations is characterised by a very large share of capital costs. As such the gross marginal and average costs of such renovations (as defined in Jakob, 2006) react very sensitively to changes in the assumed interest rates and to the time horizon. The parameter to be compared with, namely the marginal costs of heat generation, in turn depends very much on the assumed or expected energy price, averaged across the time horizon.

As shown in Jakob (2006), energy efficiency renovations are economically viable if long-term average real interest rates (3% to 3.5%) and lifetime parameters in the order of the technical lifetime of the renovations are assumed. In this case gross average costs (AC) of energy efficiency improvements of usual insulation standards vary between 0.06 and 0.09 CHF/kWh_{UE} on the level of useful energy (UE) and the gross marginal costs of heat generation vary between 0.08 to 0.09 CHF/kWh_{UE}, assuming a fuel energy price of 0.06 to 0.07 CHF/kWh.

If building owners assume clearly different parameters, i.e. if they have a shorter time horizon, if they assume nominal instead of real interest rates and if their energy price assumption is guided by the past rather by potential future developments, the outcome of such cost-benefit estimations is altered significantly. Indeed, an interest rate of 5% instead of 3.5% increases the gross marginal costs of energy efficiency by 20% to almost 30% (at constant lifetimes) and a decrease of the time horizon

from 40 to 20 years increases the gross MC by almost 40% to 50% (at constant interest rates), resulting in a combined effect of +70%. Moreover, the marginal costs of EE are determined by the actual cost level an individual owner is faced with. Due to the common practice of not inviting tenders, owners might be faced by a high cost level (typically 10% to 20%), especially in the case of advanced EE standards. Finally, the outcome of gross MC estimations is further raised if the substituted overhauling costs are neglected, typically by 30% to 50% or more (remember that the above cited values are based on the assumption that EE renovation are undertaken instead of overhauling measures). If these higher AC are then compared with the low energy price level of the 1990s (about 0.04 CHF/kWh, up to 0.055 CHF/kWh in the case of natural gas), it becomes evident that energy efficiency renovations are not undertaken and if further considerations, e.g. regarding co-benefits, are neglected.

To summarise, the economic viability as such seems not to be a barrier to undertaking energy efficiency renovations if assumptions are based on long-term and forward-looking considerations and if competitive prices are being applied, but it is a barrier if this is not.

Tax incentives

As mentioned above, the economic viability of energy efficiency renovations is rather on the edge, depending on the assumptions. Hence the question is whether the tax system tends to improve or worsen the cost-effectiveness of energy efficiency renovations.

Private individuals can deduct maintenance costs and value-increasing investments from their taxable income. Such deduction possibilities aim to create an economic incentive for both building renovation and energy-related measures, the latter being desirable from an energy policy perspective. The current models of the federal government and the majority of cantons allow special deductions from the taxable income for energy-related investments. However these measures are only specified by their character and not by the energy quality, i.e. no predefined energy-related requirements have to be met. This results in a considerable share of tax incentives being granted for the costs of measures which are compulsory by law and/or would be conducted anyway. This is supported empirically by the statements of interviewees who very rarely listed tax reasons as a motivation for the energy-related measures implemented (cf. Ott, Jakob et al., 2005 and section 5.3 below), also due to fact that owners only became aware of these incentives after having already renovated. Hence this fiscal measure is characterised by a considerable proportion of free-riders. The tax incentives in their present form are not an efficient way to promote refurbishment activity since they are largely ineffective.

There is a further drawback in the current fiscal incentive system, since it is based on deductions from the taxable income rather than on tax cut-offs or even tax credits. Indeed, due to progressive tax rates the incentives for large investments or more costly options are degressing. Further, the current system provides an incentive to spread the renovation investments over different years to optimise tax payments or tax cuts which creates an incentive to refurbish in stages rather than to do comprehensive modernisations all at once. Moreover, the fiscal incentive is higher for high income households than for low income households due to the progressive tax rates, which is in opposition to presumed incentive needs.

To summarise, the current fiscal arrangement provides some help for renovations, but incentives are not specific to enhanced energy efficiency levels. Furthermore it fosters step-by-step renovations rather than comprehensive renovations.

5.2.3 *Current market mechanisms and trends*

The diffusion of energy efficiency renovations is also determined by the current structures and the transparency of the marketplace. This applies to the real estate market, and the overhauling and renovations markets. Transactions on these markets are characterised by the fact that they occur only sporadically for most of the actors (due to the long renovation cycles and the low number of buildings per owner). This is particularly pronounced in the case of single-family home-owners.^[MS7] As such energy-efficient renovations are a credence good (cf. Sorrel et al., 2004), i.e. its benefits and drawbacks can only be experienced after the investment decision.⁵²

Market transparency, certificates and labels in the housing market

In terms of energy costs and energy efficiency the tenancy market is characterised by a considerable lack of transparency. At the moment of contract completion, house purchasers are faced with a considerable information asymmetry, due to the difficulty of estimating potential renovation costs and due to a lack of standardised information about the energy consumption of the building (such as a certified label⁵³). As a result there is no specific demand for energy-efficient buildings which could induce owners to improve the EE of their buildings.

Since renovation decisions only occur sporadically, the demand side of the renovation market is characterised by high information and search costs. At the same time, the supply side of the renovation market, namely builders and contractors (tradesmen, roofers, facade and window companies, to some extent also painters and plasterers) also tend to be relatively small. Selecting such small companies as the first point of contact may considerably restrict the scope of consultancy and the range of measures offered early on, all the more as the companies contacted are from the overhauling sector than rather than from planning sector or from the sector of specialised insulation companies (Jakob, Jochem, 2003), which restricts the potential set of renovation options.

Pioneer surcharges in the renovation market

In terms of pricing energy efficiency renovation, there is obviously a large difference between the established renovation standards and more advanced energy efficiency standards, as pointed out in Jakob, Jochem et al. (2002) and in Jakob and Madlener (2004), pp. 160 – 161. It can be concluded that advanced energy efficiency standards are still in a pioneer phase. Indeed, both renovation companies and owners have as yet had little experience in advanced standards. Due to limited experience, renovation companies are still in a phase of learning, both on the technical and on the price setting level (cf. Jakob and Madlener, 2004).

Since most companies are small and medium sized enterprises (SME), which in addition are often operating at the margin of profitability (as stated by experts from the sector), product development cannot be financed by their own resources (seen as an investment), but costs have to be covered by (pioneer) clients. Thus, pioneer clients are currently financing the process of development and learning. This– in combination with the long life cycles and the low rates of application – hinders a rapid diffusion of advanced standards.

⁵² As opposed to search goods where much more frequent purchases allow for corrections.

⁵³ Building certification and labelling is part of the European Directive of Building Performance (EPBD) and is also being discussed in Switzerland, cf. Baumgartner et al. (2004) and Rieder et al. (2006).

Demographics and the socio-cultural development trend

Demographic development in the future will result in an increase in the turnover of older SFH. In principle an increased turnover offers more frequent occasions to assess the specific qualities of the buildings and the opportunities for renovations and modernisations, particularly in the case of single-family houses. In addition, according to Ott, Jakob et al. (2005), altered requirements for dwellings could be expected from an ageing (on average) residential population with higher standards of living comfort, increasing individualisation and the future development of the workplace by portfolio workers and employees with a part-time job at home. These trends potentially lead to renovations and adaptations of dwellings, which will offer an opportunity for energy-related renovations if the modernisation follows an overall concept and reaches a certain level of intervention. Yet it remains to be seen whether these opportunities are recognised by the stakeholders and whether other barriers can be overcome (e.g. financial barriers of young families taking over older SFH).

5.3 Barriers and incentives as perceived by the building owners

The survey covered owners' past renovation works, their main motivation and their perception of the exogenous factors, including their subjective relative weighting, motivations, building-related goals and strategies, knowledge, as owner type and age, and others. Owners who have realised energy efficiency renovation were distinguished from owners who only conducted overhauling or renovations with energy relevance or did not renovate

The goal of the survey conducted in the framework of the research project (Ott, Jakob et al., 2005) was to complement the exogenous analysis and to counterbalance the findings of the background analysis (section 5.2) with the subjective view of the building owners. The survey results should allow the weighting of potential barriers according to their relevance and the identification of drivers and possible further barriers that cannot be detected by purely theoretical analytical means. Thanks to the availability of pre-information about past envelope renovations,⁵⁴ some questions were tailored to individual cases. A distinction was made between those who did not perform an energy efficiency renovation and those who did. The former were queried about reasons and barriers and the latter about motivations and drivers. This approach revealed some quite interesting insights, as is shown in the following sections. Further it was assumed that the socio-economic characteristics of owners, but also motivations and goals, have an impact on the attitude owners have towards their building and finally on renovation behaviour.

The following findings are mostly based on the samples of the survey conducted in Ott, Jakob et al. (2005) consisting of 360 SFH, in some cases on the complete samples of Jakob, Jochem (2003), consisting of 1046 SFH, mostly from the cantons of AG (17%), BE (21%), BL (15%), TG (9%) and ZH (33%). 72% of the buildings are located in an agglomeration, 64% in a community with natural gas supply and 32% in a community with the label "energy city".

Almost three quarters of buildings in the sample were constructed in 1975 or before, that is during the period when building insulation was neither mandatory nor common. Slightly more than a third of buildings date from 1946 or before (cf. Table 13). Note that buildings constructed after 1985 are intentionally underrepresented in the sample, since these buildings are much less relevant regarding the scope of the study, since they were built more energy-efficiently and are therefore less relevant

⁵⁴ The people and buildings surveyed is a sub-sample of the sample of people and buildings surveyed in Jakob, Jochem (2003).

from an energy policy point of view. Façades and walls of single-family houses were insulated at a rate of 0.4%/a to 0.8%/a between the mid 1980s and 2000 (cf. Table 12). General building conversions and extensions was conducted in 42% of the SFH during the assessment period (Table 13), and in 10% of the buildings a roof extension was undertaken.

Socio-economic variables include family situation, income, education, occupation and age (cf. Table 13). Notably 40% of the owners of the sample were more than 64 years old and that only 12% were younger than 45 years old.⁵⁵ The majority of SFH owners in the sample (n=360) are older than 50 years, with an average of 60 years. The age distribution of the owners of the buildings to be renovated (constructed before 1970) is even more skewed towards older people (cf. Table 13). In Switzerland as a whole 23% of the owners of these buildings are between 55 and 64 years old and 36% more than 64 years while only 23% younger than 45 years (based on data from census “Volkszählung 2000”, Swiss Federal Office of Statistics).

Table 13 Descriptive statistics, mean and standard deviation (in parenthesis, only for non-dummy variables), N=360

	Cat 1	Cat 2	Cat 3	Cat 4
Construction period (1946 or before 1947-1975 1976 or later NA)	0.342	0.386	0.272	
Building with flat roof	0.067			
Size of single-family house (small medium large)	0.461	0.425	0.114	
Annual income tax burden (labour income 100 kCHF, 2 children) in community of building location, given in kCHF	10.282 (2.584)			
Building extension or general conversion	0.419			
Façade or roof at the end of life time (as perceived by the owners)	0.336			
Motivation energy saving or environment	0.211			
Motivation extension of roof space	0.103			
Motivation aesthetics of façade	0.175			
Envelope strategy (comprehensive step by step overhaul. minim.)	0.072	0.297	0.422	0.178
Visited at least 1 information event	0.247			
Profession (Arch., planer builder build. mang. mercantile oth., NA)	0.111	0.086	0.231	0.617
Occupation (Arch., planer, builder, build. mang. retired other, NA)	0.194	0.231	0.617	
Education (mandatory school, apprenticeship high school, univ. NA)	0.528	0.389	0.092	
Age of respondent (less than 45 45 to 64 more than 64 years NA)	0.122	0.450	0.400	0.028
Monthly household income kCHF (< 6 6 to 10 > 10 NA)	0.303	0.406	0.169	0.122

Another interesting fact is that the age of the owners is quite strongly correlated to the age of the building; young buildings are the property of young owners and middle-old buildings are the property of older owners and only buildings constructed before the 1960 have a larger age distribution (cf. Jakob, 2004 or Ott, Jakob, 2005, p. 46). This suggests that owners construct their SFH at the age of 30 to 40 years and then own them for quite a long period. Respondents have on average owned their home for 24 years. About one third of the buildings in the sample have been the owners' property since the year of construction, i.e. they are the first owner of the building (this share is higher in the

⁵⁵ With respect to the Swiss owners of SFH constructed before 1980 the distribution is biased towards older owners; according to the population census of 2000, the share of owners who are younger than 45 years is 23% and the share of owners who are older than 64 years old is 32%.

case of younger buildings), and about half of the buildings have been purchased (particularly those which were constructed before 1960).

Financing or building professionals or owners with an occupation in the building sector comprise about 20% of the respondents. About half of them have a technical profession or an occupation related to building or construction issues. Almost 40% of the sample stated that they have a high education.⁵⁶ About 25% of the respondents visited at least one information event or a specialised fair or tradeshow, which was assumed to have a positive impact on insulation renovation modes.

Goals, strategies and motivations

Since it was assumed that intrinsic goals, strategies and motivations would have an impact on the renovation behaviour, several questions about these were included in the survey.

Regarding the closed question what is most important to them regarding their building, 63% of the respondents stated “aiming for or maintaining a high level building quality” and 33% stated “maintaining the value of their building in the long run”. Two thirds of the latter aim simultaneously at low maintenance and retrofit cost. Less than 5% stated that minimal maintenance was most important to them. Regarding the building envelope strategy (half-open question), only 7% stated that they follow a top level strategy including comprehensive renovations and modernisations; about 30% stated that they follow a strategy of step-by-step renewal, while a relative majority of 42% opted for a strategy of ongoing overhauling and 18% follow a strategy of minimal maintenance (4% did not specify their strategy). Hence there is a certain discrepancy between general goals and the strategy regarding the building envelope.

The most important reasons (triggers) for conducting energy measures are the lifespan of the building elements affected and reasons affecting specific components (aesthetics, noise, loft conversions etc.). Slightly more than 20% of the owners stated that their façade or roof renovation was motivated by environmental or energy saving considerations and slightly less than 20% by aesthetic reasons (cf. Table 13). In about 10% of cases, the motivation was an extension of the roof space.

Whereas the lifespan motivation applies for both renovation modes, the other motivations are more specific: those who insulated mostly stated environmental and energy saving reasons as relevant, whereas those who only conducted an overhauling measure did not refer to this argument at all (cf. Figure 20). Qualitatively similar findings are observed in the case of roofs, windows, and internal renovations (cf. Jakob, Jochem, 2003 or Ott, Jakob et al., 2005, pp 94 – 96).

Hence, in the case of insulation, environmental and energy considerations are mostly cited as the second most important reason (after the end-of-lifespan argument), together with other reasons such as roof space extensions or noise protection (in the case of windows). In contrast, overhauling is rather motivated by other, building-element-specific considerations such as aesthetics or construction damages, or is not specified.

The analysis regarding the impact of the age indicates that middle-aged owners (45 to 64 years) more frequently put more emphasis on general building quality. High building quality is still frequently emphasised by retired persons, but this group also states low maintenance costs as being an important element. There is also a stratification in terms of building envelope renovation strategy; up to retirement owners tend to more and more comprehensive strategies instead of step-by-step low-

⁵⁶ With respect to high education, the sample is over-represented compared to the Swiss population

level approaches, which is more frequently given by retirees (cf. Jakob, 2004 for details). Decision-finding and -making also depends on age: young owners (less than 45 years) tend to consult architects and planners more frequently whereas elder respondents tend to determine the measures directly. However, despite these impacts of the owners' age on goals, strategies and decision making, no impact on the actual average renovation rates over the period 1986 to 2000 could be detected by the renovation choice model (cf. section 5.4 below). Apparently different influencing factors balance each other out (or the data set is too small and/or not specific enough).

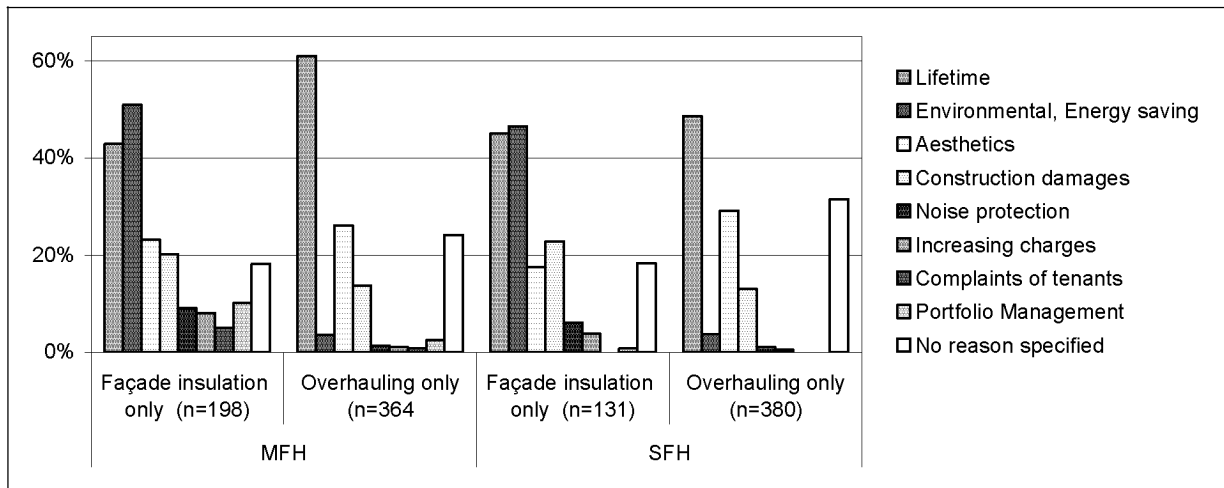


Figure 20 Share of motivational reasons stated by the owners (or managers), differentiated according to the façade renovation mode for the cases of single and multi-family houses. More than one motivation could be stated (source: Jakob, Jochem, 2003)

Information and decision making

Policy analysts and energy efficiency promoters often deplore a lack of information preventing a more prominent diffusion of energy efficiency in the building sector. Therefore the state of information and the information process was queried in the survey, based on different indicators such as the attendance at information events or visits to fairs, the type of profession or occupation, the type of consultancy, and method of defining orders and selecting contractors. The impact of each of the indicators on the relative share of renovation rates was checked.

Over 70 % have never attended an organized information or further education event and only 25% attended one or several of such events. What is interesting to note in this context is that owners state “more information” only very rarely when asked about additional incentives which would be useful from their point of view (cf. Ott, Jakob et al., 2005).

Finally, at the end of the decision-making chain is formulating an order and finding or choosing contractors, these steps often being interlinked with each other. This process can be characterised as traditionalist and informal: 60 % choose companies they have had before for renovations and 37 % take up the recommendations of friends. In contrast, to the findings above, the general process of measure defining and contractor selecting does have an impact on the decision outcome⁵⁷: the buildings of the minority of owners who stated having contracted an architect or planner were

⁵⁷ Note that the question regarding measure defining and company selecting was not specifically related to a certain measure type, but referred to renovation/renewal measures in general

insulated significantly more frequently (almost fifty percent) than those of the rest of the sample. On the other hand the insulation rate was below average if a contractor was selected to suggest measures⁵⁸ and it was also below those who defined the measures themselves before selecting a company⁵⁹.

Although there is some good reason to assume that selecting a company is somewhat endogenous to precedent motivations or decisions (those who decided to insulate might rather contract an architect than others) and that it cannot be directly seen as the origin of an insulation measure, such a selection seems nevertheless have an impact on the decision outcome. This specially applies for the case of yet undecided owners, who finally renovate less often than the average.

Drivers and barriers as seen by those who conducted EE renovations

The owners who conducted a façade or roof insulation between 1986 and 2000 were asked regarding their motivations, pointing to the fact that overhauling would have been much less costly (in terms of up-front costs). The responses of the single-family house-owners to these half-open questions revealed not one or two very important reasons, but a broad distribution of reasons. The three most frequently stated reasons are environmental and energy-saving considerations, building extensions and/or alterations, and increasing comfort of living (cf. Table 14). Remarkably a favourable cost-effectiveness or fiscal incentives were only rarely a reason for insulation measures.

Table 14 Rationale for façade or roof insulation, although overhauling would have been less costly. Share of stated selections of those single-family houses (SFH) and multi-family buildings (MFB) where such insulation was implemented between 1986 and 2000

	SFH		MFB	
	Façade	Roof	Façade	Roof
Insulation was necessary (building physics, moisture, damages)	16%	6%	32%	22%
Insulation was cost-effective, i.e. investment could be paid back	11%	13%	13%	10%
Insulation was installed due to environmental and energy saving reasons	39%	39%	38%	31%
Insulating instead of overhauling is part of the owner's basic strategy	21%	26%	38%	34%
Insulation was made in connection to building extension / alteration	30%	29%	23%	37%
The insulation measure yielded fiscal advantages	2%	0%	5%	0%
Insulation was made to improve housing comfort / comfort of living	31%	31%	Not applicable	
Insulation allowed for rent price increase	Not applicable		7%	1%
Insulation is demanded by tenants	Not applicable		5%	7%
Other reasons	7%	6%	11%	2%
No indication	5%	6%	2%	0%
Total (Multiple selections were permitted)	162%	156%	173%	144%
N (number of buildings with façade or roof insulation measure '86-2000)	61	108	56	91

Source: Jakob (2004), see also Ott, Jakob et al. (2005), p. 71 and p. 81

Most of those questioned regarding barriers experienced no financing problems during their modernisation plans (>80 %) and legal regulations have not hindered the majority doing their modernisations (92 %). This is in line with the fact that only 2.2 % of single-family house-owners

⁵⁸ This pattern was followed by one third of the owners

⁵⁹ This pattern was followed by about 40% of the owners

admitted to staggering renovations in order to avoid having to provide an energy certificate (an energy certificate is needed in the case of major conversions, extensions, alterations or renovations impacting on the envelope, but not in the case of overhauling).

Barriers as seen by those who conducted EE renovations

A considerable majority, namely about three quarters, of those who did not implement a façade or roof insulation between 1986 and 2000 answered that they did not even seriously consider doing so. Overall it is again a broad spectrum of reasons which were indicated for being the cause of not insulating cf. Figure 21.

About 30% did not see a necessity of insulating or stated that an insulation is already in place (e.g. in the case of cavity walls or roof floors). It should, however, be noted that most of the buildings in the sample are from the construction periods of the 1980s and before when insulation was not common and that Figure 21 reports on the sub-sample of owners who indicated not having insulated since 1985. Further obstacles are architectural or technical (10% to 20%) or economic reasons (about one quarter of the owners). More than one third did not specify a reason. Only about one quarter explicitly stated economic or financial barriers.⁶⁰ Within this quarter, both reasons are of about equal relevance. The policy implication of these findings is that awareness and consciousness have to be raised among a large proportion of owners. This might be done by different instruments, economic incentives being one of them.⁶¹

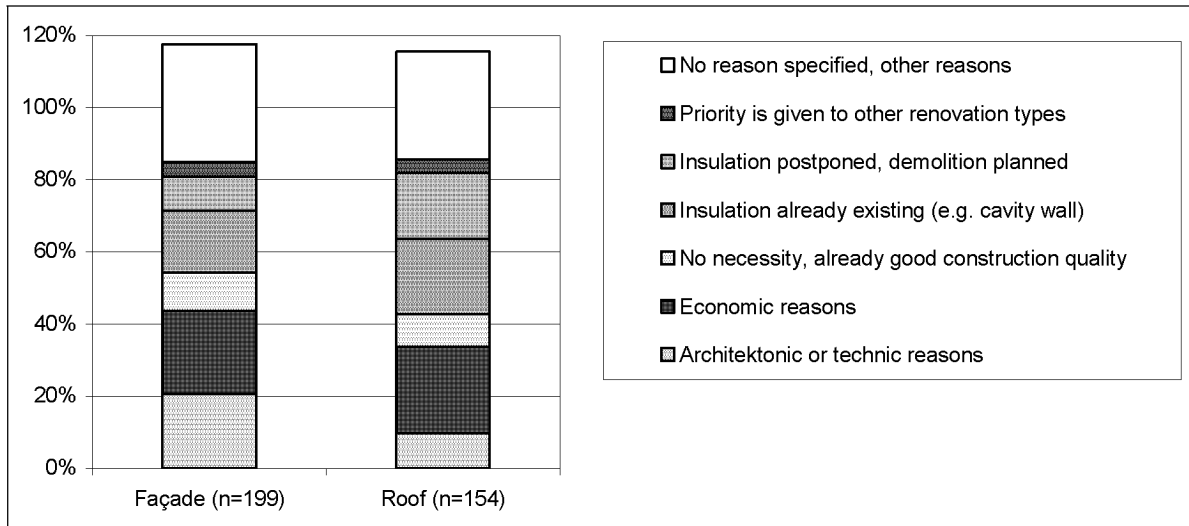


Figure 21 Share of barriers as stated by SFH-owners who did not conduct an insulation of façade or roof between 1986 and 2000. Half-open question, multiple selections were permitted (source: Jakob, 2004, cf. also Ott, Jakob et al., 2005)

Finally, owners were asked about regarding additional incentives or changes in the framework conditions that would facilitate EE renovation from their perspective. Owners did not call at all for more information and only rarely for subsidies. They rather wanted fiscal incentives instead, which

⁶⁰ This share is higher for the (small) group of those who were considering the issue of insulation: apparently economic barriers become more important if examining the subject more closely.

⁶¹ It can be assumed that (strong) economic incentives would also overcome the owners' lack of awareness.

contrasts with the actual situation. Indeed fiscal advantages for building renovation are already in place in most cantons. Here the question arises whether they are not informed about existing incentives or whether they wanted incentives in addition to the existing ones.

Comparative analysis

At this stage it is interesting to compare the outcome of the background analysis (section 5.2) with the analysis of the owners' perspectives and to check to which extent the results are congruent or eventually different from each other. This comparison is however not possible regarding all of the individual research questions and regarding each specific hypothesis; hence, to a certain extent the two approaches are complementing each other.

The overall picture of the topics where a comparative analysis is possible is characterised by some congruencies, but also by some relevant differences between the outcome of the two approaches (cf. synoptic overview in Table 15).

A fairly good congruence can be observed in terms of general renovation activity as triggering factor and in terms of regulations which are not unanimously identified as relevant barriers. Further, resemblance is observed in terms of the impact of socio-economic variables: no significance impact could be detected by the econometric model and also respondents stated such factors (e.g. too advanced age, too low income) only rarely as barriers.

To a certain extent congruence is also observed in terms of economics. From a techno-economic analytical point of view the cost-effectiveness depends on some decisive parameters such as time horizon, interest rate, and future energy prices. In some cases the outcome of the analytically calculated cost-effectiveness is positive, and in some cases negative. Taking into consideration that the mentioned parameters certainly vary between the heterogeneous owners the finding is in accordance to the outcome of the survey responses: cost-effectiveness is only quite rarely stated as driver and also only a (larger) minority stated it as a barrier.

In contrast there is a larger discrepancy regarding tax incentives. Although tax incentives may be quite considerable, particularly in the case of owners faced with a high marginal tax rate, these tax incentives are not perceived by the building owners as incentive.

Table 15 Synopsis of barriers and drivers from the analysis of the technical, legal and economic framework conditions (background analysis) and as perceived by the surveyed SFH-owners.

Barrier and or driver	Background analysis	Perception by owners
Building context		
- Physical or technical condition of façade or roof	General driver, but not specifically for EE (insulation is in most cases not essential for building operation, only "nice to have").	Strong driver (trigger) for taking action, but not necessarily for EE. In some cases also barrier to EE, particularly in case of façade.
- General renovation activity (extensions, alterations)	Extensions have significant positive impact (legal requirements).	Extensions stated as drivers (especially in the case of roof). Other renovation priorities are <u>not</u> stated as concurring barrier.
Regulations		
- Planning and construction	Generally no barrier except in some few cases (distances to neighbours, listed buildings or historical, valuable façades in city centres).	Not perceived as a barrier.
- Energy codes and standards	Could be a barrier (minimal standard required and/or energy certificate need in case of large renovations: risk of contour).	Not perceived as a barrier.
Economic, financial, fiscal		
- Economic viability	No barrier in case of long-term consideration, barrier otherwise (in case short time horizons, low energy prices, if compared to do nothing option).	Weak driver, weak to moderate barrier (generally, between 10% and 15% stated a lack of economic viability as reason for not having insulated (*))
- Financial need, access to capital	Upfront capital need is large. Basel II: still unclear. Could provide incentives (differentiated interest rates), but could also be a barrier (restricted access to capital for some owners).	Financial needs stated as barrier by some owners (between 10% and 15%) (*).
- Tax incentives	Driver: costs of EE renovations may be deducted from taxable income in most cantons and on federal level.	Not perceived as barrier nor driver, often unknown or only known after renovation (free rider effect).
Information, knowledge, other		
Information and know-how	(Technical) information in terms of brochures, websites and public consulting was available (especially in the 1990s). Economic information, short lists of companies, labels were missing.	No lack of information stated by owners (note: purchasers and tenants were not queried); only few visited information events or specific fairs, consulting sources are friends or known companies.
Choice of company		Impact on renovation mode.
Awareness, attitude, strategy		Strong driver <u>and</u> strong barrier.
Socio-economic		
- Education	Impact was assumed	No sign. impact on renovation.
- Age	Impact was assumed	Impact on goal and strategy, but no sign. impact on actual renovation.
- Income	Impact was assumed	No sign. impact on renovation.
Within the minority group of those who examined the subject more closely these proportions are about one and a half time as high		

Source: own representation, based on findings of this section and of section 5.2.

5.4 Economic modelling of renovation behaviour

The economic modelling of renovation behaviour allows the testing of hypotheses on the drivers and barriers of energy efficiency in the case of existing buildings. Such hypotheses are either derived from theory or are commonly stated by researchers and stakeholders in the field. The motivation for modelling renovation behaviour is that it provides potentially useful insights regarding the design of policy instruments which stimulate energy-efficient renovation

5.4.1 *Theoretical background and modelling approach*

The decision whether or not to retrofit the building or whether to opt for an overhauling or a retrofit that improves the energy efficiency of the building is a typical example of a discrete choice. The choice of a specific renovation type is a typical discrete decision, since homeowners have to decide for one specific type of renovation (e.g. either overhauling/painting or insulating): a linear combination of different renovation modes is not realisable. Thus, an important proportion of the models used in the literature belong to the category of discrete choice models (see for instance Sadler 2003). In the case of façade or roof, for instance, there is a quite limited number of actions that can be taken. The (reasonably) feasible set of options and its economics depend on circumstances. Some of the measures could be taken at any point in time and some of the measures are triggered by exogenous factors, typically by technical ones (need of repair or replacement).

The econometric estimation of the choice behaviour can be based on two different methods: the revealed and the stated preference method. The first method is based on the observation of the actual renovation decisions of house-owners (thus, actual market data are collected), the second method is based on information respondents give through interviews or experiments about hypothetical situations. Thus, the first method is mainly suitable for understanding the past and present behaviour, which is useful for policy or product designs that are not too far away from the set of past and present boundary conditions. The second is particularly suited to forecasting the potential behaviour of economic actors regarding new products or new boundary conditions that have not been experienced yet. Both methods have advantages as well as drawbacks (cf. for example Verhoef and Franses 2002 or Louviere et al. 2000 for further insights of the strengths and weaknesses of the two approaches).

The understanding of the past (revealed) renovation behaviour, for instance through economic modelling of the renovation decisions, is also useful regarding the drafting of future policies which appeal to new policy instruments and involve new technologies. The impact of such policies would typically be estimated using stated preference methods. Modelling revealed behaviour helps to validate stated preference models and to check the plausibility of their results. In the ideal case both model types are combined by analysing revealed and stated preferences simultaneously .

Regarding the theoretical embedding, two basic owner-types have to be distinguished, firstly the owner-occupier who experiences her or his decisions directly in terms of costs and (qualitative) housing benefits, and secondly the case of an owner-landlord, in whose case costs and benefits are transferred to and from tenants through monetary flows, depending on the tenants' willingness to pay for the respective quality impacts. In this latter case an investment decision model, perhaps including uncertainties, would be an appropriate approach (cf. Hirshleifer, 1965; Decanio and Watkins, 1998; Ford, Fung and Gerlowski, 1998).

In the basic case of an owner-occupier, i.e. in the case of a single-family house-owner (excluding the case co-property of buildings in terms of freehold flat), the renovation decision can be modelled

based on random utility theory, assuming that homeowners evaluate each renovation mode (e.g. maintenance without or retrofit with an energy efficiency improvement) and then choose the mode which leads to the highest expected utility (cf. Louviere et al. 2000; Banfi et al. 2006). The utility can be decomposed into a deterministic and a stochastic part. The choice set and the deterministic part of each renovation mode and of possible further action alternatives (including the do-nothing option), depends on its attributes (costs, lifetime, aesthetics, impact on energy efficiency and thermal comfort), on the current building situation, the current local market situation, and on socio-economic characteristics such as income, age, education, and, importantly, attitudes and expectations. Using econometric methods it is possible to identify the contribution of each attribute and of socio-economic variables on the overall choices.

If the characteristics of a given renovation mode are the same for all the individuals in the data set or where no information on the renovation modes is available, it is obviously not possible to identify the impact of such characteristics on the renovation decision. However it is still possible to model the impact of exogenous or endogenous factors on the choices made. Exogenous factors typically include building characteristics or location-specific characteristics (proxies for the local market situations) and endogenous factors typically include the socio-economic characteristics of the deciding actor, including attitudes and expectations. Thus, the utility of a certain type of renovation mode j for an individual q can be expressed as:

$$U_{qj} = U_{qj}(X, Z, H) = V_{qj}(X, Z, H) + e_{qj} \quad (16)$$

where X is a vector of housing characteristics (such as construction period, technical state of building elements, type and size of building etc.), Z a vector of location characteristics (such as canton, fiscal charge, type of agglomeration etc.), and H a vector of person specific characteristics (such as age, education, income, savings). H might also include a vector of attitude such as interest in housing quality, environmental issues, and others. The utility is decomposed into a deterministic part V_{qj} that depends on observable components (X, Z, H) and in a stochastic element e_{qj} (Louviere et al. 2000).

The probability of choosing renovation mode j can be written as

$$P(j|j, k \in A) = P\left[\left(v_{qj} + e_{qj} \right) > \left(v_{qk} + e_{qk} \right) \right] \quad (17)$$

House-owners are assumed to choose the alternative with the highest utility. That means that renovation mode j is chosen if the utility of this alternative is higher than the utility generated by all other alternatives in the choice set A .

It is assumed that the observable components $X, Z,$ and H impact differently on each renovation mode. Hence the econometric analysis of the data can be carried out using a conditional multinomial logit model (Greene 2003) or a multi-nominal probit model. In the case of more than two alternatives (feasible choices) modelling should be related to the decision structure, and in the case of the logit approach the assumption of the independence from irrelevant alternatives has to be verified. Indeed, in the case of buildings, structured decision patterns, i.e. hierarchical decisions, are quite likely. The first decision could for instance include the decision whether or not to renovate the building envelope and the second whether an overhauling or an energy efficiency renovation is chosen. Such a case is typically modelled by a tree structure .

5.4.2 *Data description and model specification*

The data used for the modelling of revealed choice was obtained from two surveys. The goal of the first survey was to estimate the annual rates of the different renovation modes of the building envelope and the heating systems and to collect some first information about drivers and barriers of energy efficiency from the viewpoint of the owners (cf. Jakob, Jochem, 2003). At this stage only very few socio-economic data were gathered, since an economic modelling was not the goal of this survey. The goal of the second survey was to reveal more precisely the drivers and barriers of energy efficiency, by specific questions that were related to the renovations as indicated by the first survey (cf. Ott, Jakob et al, 2005 and Jakob, 2004). The first survey was conducted at the end of 2001 and the beginning of 2002 and the second survey in spring and summer 2004. The estimation sample includes 360 single-family houses. Descriptive statistics of the sample of single-family home-owners are displayed in Table 13, section 5.3, p. 81).

Due to the relatively low number of buildings and due to the low rate of energy efficiency renovations the choice variables covered a period of several years, namely 1986 to 2000. This period might seem quite long, but it should be noted that this period was quite stable in terms of framework conditions (energy prices did not vary much after 1986). Further, some renovation modes were aggregated to restrict the number of coefficients to be estimated and only the one of highest interest, namely the opaque building envelope, was kept. In 22.5% of the single-family houses in the sample an insulation of the roof, the roof space or the façade was performed and in 25% an overhauling without any insulation (cf. Table 16). In the remainder of the buildings, other types of renovations such as window replacement or internal renovations or no renovations were performed.

Some of the buildings with outcome 3, i.e. buildings whose façade or roof was neither insulated or overhauled during 1986 and 2000, include façade or roof insulation or overhauling before 1986. For clarity, i.e. to obtain a clear-cut observation period, and to avoid noise (respondents might have confused renovation insulation with insulation at the construction of the buildings) the corresponding 37 observations were dropped from the estimation sample.

Table 16 Choice of renovation mode choices of single-family house-owners between 1986 and 2000

Outcome	Description	Count	Share
Outcome 1	Insulation of façade and/or roof	81	22.5%
Outcome 2	Overhauling of façade and/or roof, but none of them with insulation	91	25.3%
Outcome 3	Other kinds of renovation or no renovation	188	52.2%
Total		360	100.0%

Before designing the survey questionnaire we worked out several hypotheses about potential impacts on renovation choices. The drivers of the insulation mode can be grouped into the following categories: technical, attitude/motivational, socio-economic, and locational.

The age and the state of the building and its components presumably have a strong impact on the renovation activity of the owners. As compared to younger buildings which were insulated during their construction, one can expect increased rates of the insulation mode for buildings from the whole construction period 1975 and before, and possibly particularly high rates for the boom period 1946 to 1975 which was characterised by a particularly low construction quality in terms of thermal comfort, thus creating a corresponding need to catch up. Due to assumed heterogeneity and possible former

renovations the objective variable “construction period” was complemented by a subjective variable “element has reached end of its life time”, as perceived by the owners.

Further, it can be expected that other types of renovation and housing activity, typically inside the building, impact on the renovation or overhauling of the building envelope. This impact could be negative or positive: either insulation is in competition (financially and economically) with other (large) renovation projects, or it is triggered by other types of renovation or building works. Indeed building experts put emphasis on the fact that insulation is not a primary motivation for initiating renovations (due to the lack of cost-effectiveness if solely undertaken with the aim of energy saving), but that renovation activity tends more often to be induced by needs such as additional or altered space.

Building insulation is a quite specific type of renovation due to its typical add-on character. Thermal insulation is rarely indispensable to the running of a building, except for some cases of the boom construction period. Although it provides other important benefits (such as thermal comfort, see Banfi et al, 2006), insulation is primarily seen as an energy efficiency measure, reducing energy costs and improving environmental performance. Hence it can be assumed that owners that are environmentally concerned or intrinsically convinced that individual action is needed would insulate more frequently than the rest of the population. Accordingly, we queried owners regarding their specific motivations. In addition, we assumed that owners with high education tend to be more environmentally concerned and that they could better estimate the potential benefits of building insulation.

Regarding further socio-economic variables, it was assumed that financing or building professionals or an occupation in the building sector would have a positive impact on renovation activity. Furthermore, visits to information events or specialised fairs or tradeshow was assumed to have a positive impact on the insulation renovation mode.

Building insulation renovations are characterised by a considerable upfront financial demand, which is then amortised over a long period of time. Therefore it can be assumed that owners with high income choose this type of renovation more frequently than those with low income. Further, due to the long time horizon we assumed that aged and/or retired owners would chose the insulation mode rather less often, firstly because of the irreversible character of the investment and secondly because monetary pay-back flows are delayed too long.

Finally it was assumed that the location of the building impacts on the renovation choice. A distinction was drawn between the cantonal and the communal level. In Switzerland, cantons have a large independence in terms of general fiscal policy and energy policy in the building sector. There are different rules in various cantons regarding deductions for renovation and overhauling costs from the taxable income, and cantons may define individual mandatory standards and – more relevant for the case of renovation during 1986 to 2000 – may define their own subsidy programs. Further, the income tax burden varies between cantons and communities. To test for these factors, we defined dummy variables for cantons and included the income tax burden for a typical owner (annual household income 100'000 CHF, 2 Children) as a community-specific variable.

Two models are specified. The full model includes the same variables as the reduced model, but additionally specific “event-type” variables for the building elements considered (e.g. roof space extension, damage) and attitude and motivation variables (e.g. general regarding goals and strategies, end of lifetime of the building element as perceived by the owner). The reduced model includes only general and “objective” variables, that is, general characteristics of the building and its location

(community and canton) and of the owners. This approach was chosen to test the robustness of the model results by omitting event-based and subjective variables (and to test for endogeneity).

To use a simple multi-nominal logit model rather than a probit model, a nested structure or an error correlation approach, the IIA assumption, that the relative odds of any two outcomes are independent of the others (in the case of three of the others), has to be tested. This was verified for all models with the Hausman and the Small-Hsiao test of STATA. Omitting outcome 1 or outcome 2 did not change the relative odds in a statistically significant way, which means that the IIA assumption holds. For model 1, for instance, $\text{Chi}^2(\text{df}=11)$ of omitting outcome 1 = -3.26 and $\text{Chi}^2(\text{df}=11)$ of omitting outcome 2 = -1.3.

5.4.3 Estimation results and discussion

The estimation results for outcome 1 (façade and/or roof insulation) are displayed in the upper part of Table 17 for two different multi-nominal logit models and in the lower part for outcome 2 (façade and/or roof overhauling). The reference case (outcome 3) is for other kinds of renovations or no renovation during the considered period (1986 to 2000).

The results of both models are generally plausible. Many, but not all, coefficients vary from 0 to a statistically significant degree. Let us first focus on outcome 1, which is the outcome of particular interest from an energy policy point of view. In model 1 the estimated coefficients of building characteristics have the expected sign and they are – with a single exception – statistically significant. The exception is the construction period 1947 to 1975, which, however, is plausible in the sense that the construction period before the mid-seventies can be considered as rather uniform. Buildings with a flat roof were insulated more frequently. Hence the opportunity of the repair of these roofs was used to improve the insulation.

The coefficients of the more specific building-specific variables introduced in model 2 generally show a (highly) significant impact on the renovation modes: insulation is installed more frequently in the case of roof space or building extensions or alterations, if the building element reached the end of its lifetime (from the owner's viewpoint), and if construction damage at façade or roof had occurred. Finally, and important to note, intrinsic variables of a more general character such as building envelope strategies or general building quality goals⁶² do not show a significant impact on the renovation modes.

The assumption that socio-economic variables such as income, age and education would have an impact on the renovation modes could not be confirmed by the estimations. Hence owners with high income or high education or owners following a top-level quality strategy did not insulate more frequently⁶³, and elderly persons did not insulate less frequently, as one could assume. Eventually this latter finding could result from a data artefact (during the assessed period of 15 years many of the respondents were still younger than 65 years old). The same applies for further indicator variables such as the general quality goal that owners have regarding their building, their building envelope strategy, or whether they have visited energy information events or not. Apparently more specific

⁶² The variable regarding general quality goals was tested, but not included in the models displayed in Table 17.

⁶³ This could be due to the discrepancy between stated general goals and the stated strategy regarding the building envelope (cf. data description sub section).

variables such as perceived lifetime overruled the impact of more general variables such as goals and strategies.

Table 17 Estimation results of the multi-nominal logit models of revealed renovation mode choices of single-family house-owners (N=323)

Outcome 1: Façade or roof insulation	Model1			Model2		
	Coeff.	(SE)	Sig.	Coeff.	(SE)	Sig.
Outcome 1: Façade or roof insulation						
Construction period 1947-1975	0.22	(0.34)		0.82	(0.42)	**
Construction period 1976 and later	-2.06	(0.46)	***	-0.81	(0.57)	
Building with flat roof	1.85	(0.61)	***	1.20	(0.71)	*
Large single-family house	0.89	(0.47)	*	0.71	(0.56)	
Income tax burden (100 kCHF, 2 children)	-0.05	(0.06)		-0.04	(0.07)	
Building extension or conversion	n.i.			1.39	(0.39)	***
Extension of roof space	n.i.			2.33	(0.65)	***
Construction damages at roof or façade	n.i.			2.41	(0.56)	***
Façade or roof at the end of life-time (perceived)	n.i.			1.67	(0.39)	***
Comprehensive strategy regarding envelope	n.i.			-0.08	(0.72)	
Age of respondent more than 64 years	-0.05	(0.34)		0.34	(0.40)	
Household income	0.00	(0.43)		-0.01	(0.51)	
Education University or High School	0.05	(0.32)		-0.01	(0.38)	
Respondent visited at least 1 information event	0.35	(0.35)		0.45	(0.43)	
Occupation: architect, planner, builder, build. manag.	-0.49	(0.44)		-0.72	(0.53)	
Constant	0.07	(0.75)		-2.43	(0.95)	**
Outcome 2: Façade or roof overhauling (painting)						
Construction period 1947-1975	0.91	(0.35)	***	1.27	(0.40)	***
Construction period 1976 and later	-0.49	(0.38)		0.40	(0.47)	
Building with flat roof	0.65	(0.68)		-0.12	(0.75)	
Large single-family house	0.46	(0.49)		0.52	(0.52)	
Income tax burden (100 kCHF, 2 children)	-0.12	(0.06)	**	-0.14	(0.06)	**
Building extension or conversion	n.i.			0.23	(0.36)	
Extension of roof space	n.i.			1.23	(0.72)	*
Construction damages at roof or façade	n.i.			1.78	(0.56)	***
Façade or roof at the end of life-time (perceived)	n.i.			1.78	(0.37)	***
Comprehensive strategy regarding envelope	n.i.			0.20	(0.71)	
Age of respondent more than 64 years	0.46	(0.32)		0.64	(0.36)	*
Household income	0.36	(0.40)		0.32	(0.44)	
Education University or High School	-0.84	(0.32)	***	-0.77	(0.35)	**
Respondent visited at least 1 information event	-0.19	(0.36)		-0.18	(0.40)	
Occupation: architect, planner, builder, build. manag.	0.01	(0.40)		-0.03	(0.44)	
Constant	0.57	(0.69)		-0.59	(0.83)	
Pseudo-R ² Log likelihood Chi ² (df)	0.11 -303.2 77.9(20)			0.25 -2510 174.2(30)		
Significance levels: ***=1%, **=5%, *=10% n.i.: not included in the model						
Reference Outcome: No renovation or renovation, window renovation or internal renovation						
Reference construction period: before 1947						

Comparing the estimation results between outcome 1 (insulation) and outcome 2 (overhauling) also quite yields plausible results. Damage and lifetime considerations of the building elements are relevant for both outcomes, since both modes allow for a corresponding repair and improvement; see the section regarding the marginal effects of evaluating the relative intensity of the impact on the choice. The community-specific income tax burden has a negative effect on outcome 2 (the coefficient for outcome 1 is also negative, but not significantly different from 0), which means the renovation activity lowered by the community tax burden; interestingly, the overhauling mode is more affected than insulation mode. Note that this is in line with other findings concluding from the model presented here or from additional questions of the survey (cf. Ott, Jakob et al, 2005): insulation is not so much motivated or hindered by economic factors as by technical (damage, lifetime of components), personal (attitudes such as environmental concerns) or occasional factors (building extensions).

The canton of the building location was also tested. In the models with intrinsic variables, none of the dummies for the main canton was significantly different from 0 (only the dummy for other cantons was, but less than 5% of the sample are in those cantons) and in the models without intrinsic variables in only one exception (SFH in the canton of TG were less frequently insulated). Also other location-specific variables on the community level such as tax revenues per inhabitant, community type (agglomeration or not), energy city, and others, did not show a significant impact on the renovation choices.

Comparing the actual versus the predicted outcomes allows for a characterisation of the predictive power of the estimated models. The share of correct predictions is quite low in the case of the first model without specific and intrinsic variables, in particular for outcome 1 (insulation). Indeed, it only predicts 28% of the outcome 1 correctly (cf. Table 17), which is even less than a model that contained only a constant (in this case about 33% would be predicted correctly). The predictive power of model 2, which includes specific and intrinsic variables, is much higher, not only for outcome 1, but also for outcome 2. The predictive power of model 2 can be characterised as quite good, given the relatively few observations and relatively few and rather general variables (particularly, no specific information on the renovation modes such as costs was available). Finally, model 2 also performs much better in terms of Chi² and in terms of pseudo R² (it is 2.5 times higher than model 1).

Table 18 Actual outcomes vs. predicted outcomes

Actual		Model 1				Model 2			
		Outcome 1	Outcome 2	Outcome 3	Share correct	Outcome 1	Outcome 2	Outcome 3	Share correct
Outcome 1	81	23	12	46	28%	45	17	19	56%
Outcome 2	91	7	37	47	41%	17	42	32	46%
Outcome 3	151	14	21	116	77%	10	15	126	83%
Overall	323	44	70	209	54%	72	74	177	66%

In the case of dummy variables the marginal effects are defined as the difference of the predicted probabilities of the two states of the corresponding dummy variable (0 or 1). This difference is estimated at the sample mean, i.e. all the other variables are set equal to the sample mean. In Table 19 the marginal effects (ME) are given for outcome 1 and outcome 2; the ME of outcome 3 can easily be calculated due to the fact that the ME of all three outcomes sum up to 1 for a given variable.

The probability of renovation is strongly increased in roof and building extensions and conversions and by lifetime considerations (+14% up to +36%), cf. Table 19. With one exception, these variables

impact more strongly on outcome 1, i.e. on the insulation mode, the exception being construction damage, which impacts more on the overhauling mode. Hence the end of the lifetime of a building element stimulates renovation, but not exclusively energy-improving renovation. The probability of overhauling renovation without energy improvement is also increased in the case of the middle-aged buildings constructed between 1947 and 1975 (+22%), except for those with a flat roof.

Table 19 Marginal effects (ME) of significant variables ($p < 0.1$, cf. Table 17) on choice probabilities of outcomes 1 and 2, at the sample mean

Outcome 1: Façade or roof insulation	Model1		Model2		Outcome 1		Outcome 2	
	ME	(SE)	ME	(SE)	ME	(SE)	ME	(SE)
Construction period 1947 to 1976			0.18	(0.07)	0.04	(0.06)	0.22	(0.08)
Construction period 1976 and later	-0.27	(0.05)						
Building with flat roof	0.35	(0.12)			0.26	(0.14)		
Large single-family house (more than 180 m ²)	0.14	(0.09)						
Income tax burden (100 kCHF, 2 children)			-0.02	(0.01)			-0.03	(0.01)
Building extension or conversion	n.i.		n.i.		0.23	(0.06)		
Extension of roof space	n.i.		n.i.		0.36	(0.11)	0.00	(0.11)
Construction damages at roof or façade	n.i.		n.i.		0.14	(0.06)	0.25	(0.07)
Façade or roof at end of life-time (perceived)	n.i.		n.i.		0.29	(0.09)	0.12	(0.09)
Age of respondent more than 64 years							0.12	(0.07)
Education University or High School			-0.17	(0.05)			-0.16	0.06
n.i.: not included in the model								

High education has a negative impact on the probabilities of the overhauling mode; the probability is lowered by 16%. Since the corresponding variable of outcome 1 was not significantly different from 0 (and the coefficient is almost 0), it can be concluded that this lack of overhauling is not compensated by more frequent insulations but by other types of renovations (windows, internal etc.) or by the doing-nothing option (outcome 3). As mentioned earlier, the remaining socio-economic variables do not impact on the envelope renovation modes. Apparently, education, income, and occupation do not stimulate energy efficiency renovations. Note finally that the marginal effects of the additional models that include the canton dummies (not presented here) are similar to the ones in Table 19.

The model presented in this section is a first attempt to model the renovation choices of SFH-owners in Switzerland. Due to limitations in the data set further research is needed to deepen the understanding of the renovation behaviour. Further variables such as other large expenses and energy prices should be made available and some of the existing variables should be clarified. It should also be investigated to which extent some of the variables used are endogenous.

Unfortunately no energy price impact could be detected with the available data set. Indeed, between 1986 and 2000 the consumer price level of heating oil and natural gas was quite constant. Price increases, e.g. due to the first gulf war, were of quite short period and did not have a lasting impact on the beliefs of the private single-family owners. In addition there was no distinct signal towards energy price measures, for instance a CO₂ tax, during that period. Since 2000 the situation is somewhat different, due to a strong increase of the oil price, due to an emerging debate on resources and extraction/refinery capacities and due to a more intensive climate change debate. It is planned to

conduct a similar study as presented here for the case of multi-family buildings including the period as from 2000.

5.5 Summary, discussion and conclusion

In this paper the barriers and drivers of energy efficiency in the case of single-family house (SFH) renovations were addressed by three approaches, namely by an analysis of the technical, legal and economic framework conditions, by a survey that gathered the subjective perceptions of these framework conditions as well as the motivations of the SFH-owners, and by the econometric modelling of the revealed renovation choices. Consistency between the three approaches was observed in terms of some, but not all barriers and drivers.

The analyses consistently revealed that building envelope renovation is triggered by general renovation activity such as building extensions or alterations, by the end of the lifetime of the element and by energy saving and environmental concerns. It is only the latter that leads to significantly more energy-efficient renovations. Consistency was also observed in terms of regulations, which are unanimously not identified as relevant barriers, and in terms of information; during the period considered technical information in terms of brochures, websites and public consulting was available (especially in the 1990s) and owners did not criticise a lack of information.

Regarding economic, financial and fiscal factors some consistency, but also some discrepancy can be recorded. The finding from the survey responses that economic viability is only quite rarely stated as a driver and also only by a minority as a barrier is more or less in accordance with the cost-benefit analysis using empirical data from the literature (Jakob, 2006). Consistency is given especially if it is taken into account that some decisive parameters such as time horizon, interest rate, and future energy prices certainly vary between the heterogeneous owners. Indeed, the variation of these parameters leads either to a negative or a positive outcome of a cost-benefit analysis which explains why some owners stated economic factors as a barrier and other did not. Remember that owners stated the high financial demand as a barrier to EE about equally often as the economic viability.

A discrepancy between the different approaches is observed regarding tax incentives. The analysis of the fiscal ordinance revealed large incentives but these incentives were perceived by the survey owners only to a very limited extent and often only after renovation decisions. A discrepancy was also observed in terms of the impact of socio-economic variables: such impacts were expected from the theoretical background, but no significance impact could be detected by the econometric model and also respondents stated such factors (e.g. too advanced age, too low income) only rarely as barriers. Apparently, other considerations that are not directly correlated with these basic socio-economic variables overrule their impact.

Indeed, the survey revealed a very relevant outcome, namely regarding awareness, attitudes, motivations, goals and strategies. A remarkably large majority of the owners did not even address the question whether to insulate or not. This applies not only to those who did not undertake any type of renovation, but remarkably even to those who actually undertook some envelope measure.⁶⁴ Renovation behaviour is quite strongly determined by the fact whether owners see a need for insulation or not (if they addressed the question at all) and by environmental and energy saving and

⁶⁴ This may also explain the (unexpected) result that owners did not perceive a lack of knowledge and information, apparently they did not give a great deal to the subject.

by comfort of living considerations. Either the necessity for modernisation is derived from these factors or, alternatively, the need is not perceived; owners stated that the building is in good condition, that thermal insulation exists (although on a low level), or that insulation is “not necessary”.⁶⁵ Economic reasons such as energy cost savings or fiscal advantages were stated much less frequently as a reason to insulate. These findings reveal a considerable lack of awareness and imply that awareness raising is very relevant and must be one of the first serious steps of policy actions.

Overall, the variety of obstacles and motivations stated by the owners is quite broad, including environmental/energy saving, technical and economic reasons. Opportunities and occasions such as building and space extensions and internal motivations are relevant drivers of EE renovations rather than information, education or high income which do not show a significant impact on the renovation choice. To summarise concisely: it is conviction rather than economics that have driven building insulation so far, and it is a lack of consciousness and partly economics that have hindered building insulation in the past.

In view of the market structures observed and the common practice of decision making, renovation behaviour can be described as being strongly oriented on previous experiences. Innovations tend to diffuse via personal, word-of-mouth recommendations.

The renovation choice modelling reveals that technical building characteristics such as building age, damages to building elements and triggering events (such as building alterations and extension) have a very strong impact on the choice of renovation modes. Their impact is much more relevant than those of socio-economic variables such as income, age, education, professional occupation, general quality goals or information indicators whose impact on the renovation modes could not be confirmed by the estimation results. Hence owners with high income and high education, or owners following a top-level quality strategy seem not to insulate more frequently and older people did not insulate less frequently, as one might have assumed. These findings from the modelling of the renovation choices are quite consistent with the conclusions that can be drawn from other survey questions. On the one hand, energy-efficient renovations were motivated by environmental and energy-saving considerations or by building extensions/alterations rather than by economic or fiscal advantages. On the other hand, in terms of the non-adoption of EE renovation, the lack of awareness or necessity played a more relevant role than the lack of cost-effectiveness or the lack of financial resources or other barriers.

Policy implications and recommendations

A lack of information was not revealed from the survey answers nor from the econometric modelling. Note however that economic information, short lists of certified products companies, and labels was missing during the considered period. Hence there is not a lack of information in terms of quantity and even not in terms of quality, but rather in terms of the adequate type of information to increase market transparency and to reduce transaction costs.

Hence, owners and even more building purchasers must be provided by simple, but a timely and highly credible information about the EE level of the building, typically provided by energy certificates, (categorising) labels⁶⁶ or information about standardised annualised future energy costs.

⁶⁵ Although their buildings were constructed before the mid 1970s and they had not insulated since then.

⁶⁶ A label such as Minergie or Passivehouse is helpful, mainly in the case of new buildings, but due to its top-level target not suited to covering the whole housing market.

Useful and adequate information is also generated by lists of EE buildings or by short lists of certified companies and professionals (as for instance realised to a certain extent by the Minergie-association). Such information is particularly valuable since private owners only very rarely are in a decision situation (due to the long lifetime of building components and due to the low change rate of ownership). The builders and contractor companies as first contacts and multipliers therefore have also to be incorporated as a target audience in campaigns for sustainable renovations in the building sector. Public involvement in the field of information and market transparency is justified among others due to the ancillary and external benefits provided by such efforts (cf. Sorrel et al., 2004).

Finally, regarding economic incentives, two barriers have to be addressed, namely the economic viability that is not given for all the owners in their perspective, and the high upfront financial demand. These barriers can be addressed simultaneously either by subsidies or by fiscal incentives. Although a CO₂-tax or energy taxes would address only the economic viability barrier, it is recommended to implement such a tax in combination with the subsidy and the fiscal incentives. Indeed, such a tax ensures owners regarding their long-term investments and tax revenues can be used (partly) to finance subsidy or fiscal incentive programmes. To lower free-rider effects such programmes should require minimal energy efficiency standards.

Regarding the current tax incentive system adjustments are needed if such tax incentives should play a role as a EE policy instrument, for instance as a surrogate for subsidies, if such are judged to be necessary. It is indispensable to make such incentives more known so that owners can include them in decision making. It is recommended to implement a tax credit system rather than a system of deductions from the taxable income. In a tax credit system, the fiscal incentive is provided by a reduction of the tax due. If the tax due is low or even zero, the incentive is spread over several years or even paid as a cash contribution. Such a system overcomes the considerable disadvantage from deductions of the taxable income, in which incentives increase with high income and decrease with low income. In contrast, with a tax credit system the incentive is – at least in absolute terms - constant for all income groups (tax credit systems are in place in France, the US, and in other countries).

CHAPTER 6

CONCLUSIONS, POLICY RECOMMENDATIONS, CRITICAL REMARKS AND PERSPECTIVES

In this chapter 6, first a summary and conclusions from a content point view are given. These are followed by conclusions from a methodological point. Then suggestions for policy measures to promote energy efficiency in the buildings sector are made. The chapter concludes with critical remarks and with suggestions for future policy analysis and research.

6.1 Summary and conclusions from a content point of view

The starting point of the analysis was the observation that opportunities and advantages of energy efficiency potentials are frequently not taken, particularly in the case of existing residential buildings. The question was whether this behaviour is in contradiction to the low costs of energy efficiency investments as claimed by energy efficiency promoters and environmental groups, or whether it could be explained by an underestimation of the costs by these actors, i.e. by a lack of cost-effectiveness, or by other endogenous or exogenous decision parameters such as individual preferences and tastes or inadequate legal, fiscal, or financial boundary conditions. Answers to these questions should then provide the foundation for policy measures to adjust boundary conditions to tap possible cost-effective potentials and to promote enhanced energy-efficiency at least to the levels at no or moderate additional costs from a societal point of view.

The economics of energy-efficiency measures in the residential buildings are somewhat more complex than those of many energy conversion technologies, mainly due to the multi-dimensionality of the benefits they generate and due to their add-on character. This difference in functionality between energy converting technologies (just one function to convert final energy to useful energy) and efficiency changes at the useful energy level (like in buildings which have several functions such as shelter, protection against theft or noise) is often overlooked and often leads to partial economic evaluations of efficiency investments. The add-on character of energy efficiency investments implies that these options not only compete with the related option of heat or cooling production, but also with completely different consumer wants such as prestigious entrances, subterranean garages, cars, vacations, and others. Further, in contrast to energy conversion (i.e. the generation and distribution of final energies), the final energy use of the residential sector is determined by a large number of individual decision-makers (almost all single-family houses are privately owned and two thirds of the multi-family are in privately owned buildings) most of them having little or no knowledge about energy technology issues. Finally it became evident that the economic analysis should distinguish between the private and the societal perspective.

This broad spectrum of research questions was structured into several research topics which have been addressed more or less independently, having in mind, however, their interrelationship and

their relative significance within the super-ordinate problem addressed. It is in particular the topic presented in CHAPTER 5 which integrated findings of the previous chapters and has established the basis for the formulation of policy recommendations (cf. section 6.2).

Techno-economic estimation of marginal costs of energy efficiency

The techno-economic marginal or average costs of investive energy efficiency measures – expressed as discounted investment and maintenance costs per gained energy efficiency unit – depend quite strongly on some (few but decisive) parameters, namely the time horizon considered, the interest rate assumed, and the reference investment case considered. The outcome of the techno-economic cost-benefit (CB) evaluation⁶⁷, i.e. the comparison of the marginal costs of energy efficiency with the marginal costs of energy (e.g. heat) generation is positive if a long-term perspective is taken (by using long life times of the components invested) and if the future energy price is not assumed to be as low as in the 1990s (0.04 CHF/kWh_{FE}, i.e. 40 CHF/100 lit of heating oil) but rather at the current (2006, early 2007) level of 0.07 CHF/kWh_{FE} (70 CHF/100 lit). The outcome of the CB evaluation is negative if time perspectives are assumed that are significantly shorter than the building elements' lifetime, if higher interest rates are assumed or if the substituted overhauling costs are neglected.⁶⁸

It should, however, be stressed that the average costs of EE with increasing efficiency levels are quite flat. The policy implication of this outcome is that economic incentives such as a CO₂-levy could be made dependent on current energy prices. Implementing a lower bound for energy prices, e.g. 0.08 CHF/kWh_{FE} taking into account the private perspective, would ensure investors and owners and assure pay-back of their investments.

In contrast to insulation measures, housing ventilation systems cannot be paid back with reduced energy costs alone, even in the case of new buildings and if low interest rates and high future energy prices are assumed. Indeed, the MC of EE of housing ventilation systems with heat recovery in low-energy buildings would be clearly above 0.2 CHF/kWh_{UE} if benefits such as fresh air or improved noise protection were neglected (see below).

Considerable techno-economic progress

Regarding long-term policy goals and priority setting based on economic considerations it is important to know that the costs of technologies are not static but change over time due to changing market conditions and particularly due to techno-economic progress of the components considered.

The survey of historical data back to the 1970s revealed a considerable techno-economic progress of energy efficiency investments. Technical progress factors were estimated at 3% per annum for wall insulation and 3.3% p.a. for windows, based on Swiss data that cover the past 30 years. Simultaneously average real prices have decreased by 0.6% per year since 1985 for façades, and 25% over the last 30 years for windows, resulting in progress ratios (pr) for wall insulations between 0.8 and 0.85 for the time period 1975–2001 and for double-glazed coated windows in the range of 0.83–0.88 for the period 1985–2001, (cf. Chapter 3). These results point to a considerable techno-economic

⁶⁷ Neglecting at this stage further cost elements such as transaction costs, but also co-benefits such as increased thermal comfort.

⁶⁸ In all cases the MC and AC of EE investments depend on interest rates and time horizons. An interest rate of 5% instead of 3.5% increases the gross marginal costs of energy efficiency by 20% to almost 30% (at constant lifetimes) and a decrease of the time horizon from 40 to 20 years increases the gross MC by almost 40% to 50% (at constant interest rates), resulting in a combined effect of +70%.

progress, which is likewise observed in the case of new electricity generation technologies in the phase of market introduction and the take off phase (UNDP/WEC/UNDESA, 2000; Kümmel, 1999, Neij 1997 and 1999, McDonald and Schratzenholzer, 2001, Wörlen 2003).

The observed techno-economic progress is due to increasingly stringent building codes and standards and environmental concerns rather than due to fiscal or other economic incentives. Starting from the early 1980s and in line with technological progress, public authorities in cooperation with intermediaries (e.g. privately organised professional associations such as SIA) have pushed building standards that have been gradually adopted by policy-makers and eventually incorporated into jurisdiction as legally binding standards in an inter-cantonal diffusion process. The techno-economic progress achieved due to codes and standards for new buildings have also affected the renovation practice of existing buildings .

Valuating the total benefits of energy efficiency building attributes

Many building energy efficiency measures, particularly building envelope measures and housing ventilation systems simultaneously yield several benefits. Next to energy efficiency gains these benefits include improved thermal comfort and air quality, protection from external noise or theft. The economic appraisal of the owners' and tenants' valuation of these benefits, based on stated preferences, showed a significant willingness to pay (WTP) for the total benefits of energy-efficiency-attributes of rental apartments and of purchased houses. The WTP varies between 3% of the price for an enhanced insulated facade (in comparison to standard insulation) and 8% to 13% of the price for a ventilation system in new buildings or insulated windows in old buildings (compared to old windows) and include both the energy efficiency gains and the co-benefits.

The WTP values are generally higher than the costs of implementing these attributes. In particular, this applies to housing ventilation systems which were found not to be cost-effective from a pure energy efficiency viewpoint (cf. Chapter 4). From this finding it can be concluded that – next to energy cost savings – co-benefits significantly contribute to the total economic valuation of these systems. Hence, basing the promotion of the 'Minergie' label on such co-benefits is economically well founded.

Drivers and barriers

Barriers against a more prominent diffusion of EE are mainly relevant in the case of existing buildings.⁶⁹ From the corresponding analysis it can be concluded that EE renovation is not hindered by one single predominant obstacle, but often by several barriers. Among these, lacking awareness of opportunities and lacking of consciousness were identified as one of the most relevant. This seems to be related to the structure of the building owners which largely consist of private persons who only own one or very few buildings and are therefore faced only rarely to renovation issues (due to the long life-time of the building elements). This also impedes a professional approach to building management and leads to high information and search costs.⁷⁰ This is amplified by a lack of transparency on the real estate, housing and tenancy market where the EE of buildings is neither standardised nor made explicit in tendering and contracts. Further, typical decision making patterns

⁶⁹ Barriers also occur also in the case of the construction of new buildings, but they can be handled more easily by policy measures (e.g. mandatory standards) and options are evaluated more carefully, especially in the case of owner-occupiers.

⁷⁰ A further structural barrier is the size structure of the construction and renovation companies, small companies cannot take advantage of economy of scale or economy of mass-production and a lack of "critical mass" might also lead to a lack of innovation.

(e.g. focus on investment costs instead of life-cycle costs, company selection) and the structure of the construction and renovation sector reasons also strongly determine the renovation behaviour: a considerable share of owners choose directly a contractor (e.g. painters and roofers) often offering options at low investment cost (and low efficiency impact) in order to get the bid.

Economic barriers such as a lack of cost-effectiveness or financial hurdles (lack of own capital or limited access to capital) play a certain, but not major role. The outcome of analysis of the drivers of energy-efficient renovations was qualitatively quite similar: it is not one predominant cause that drives EE renovations, but several roughly equally important ones. Intrinsic motivations such as environmental and energy saving concerns and housing comfort improvement rather than on economic considerations, fiscal advantages, tenants' demands or socio-economic characteristics etc. seem to drive EE renovations.

The finding clearly indicate that it is not the economics that driven or hindered building insulation in the residential buildings so far, and that a lack of consciousness of building owners and the construction sector have played an important role hindering energy efficiency investments in residential buildings on a large scale in the past few decades.

In terms of policy implications the outcome of the economic analysis of EE in the residential sector is quite coherent: The flat character of the life cycle cost curve as a function of increasing energy efficiency (Chapter 2) and the asymmetric risk exposure of low insulation levels justify the promotion of enhanced standards resulting in decreasing costs due to the experience curve effect (Chapter 3). Next to mandatory building codes and standards the WTP of certain market segments for EE building attributes (Chapter 4) can be utilised to go down the experience curve to some and to induce diffusion into the renovation market.

Conclusions from a methodological point of view

The research was based on several methodological approaches. Some of them had to be adjusted to specific needs and peculiarities of energy efficiency in the building sector. The bottom-up techno-economic approach leads to the conclusion that including up-to-date building physics methods are necessary to assure the accuracy of the bottom-up estimates of marginal costs of advanced EE measures.

Neglecting construction details in terms of costs and building physics induces a significant under-estimation of the MC of EE. Conversely, an over-estimation of energy savings is likely would have resulted if EE investments had not been put into their context, i.e. if they were not compared to typical reference cases which represent the current practice of building construction, operation and maintenance.

The techno-economic approach chosen yielded also some limitations, namely in the case of evaluating multi-dimensional impacts and benefits. These are more suitably addressed by statistical (econometric) methods. Several potential methodologies to appraise the economic benefits of energy-efficient buildings and renovations from a building user perspective were examined. It was found that the choice experiment method is a suitable method to appraise the willingness to pay (WTP) for well introduced (insulation, windows) and new energy efficiency attributes (ventilations). Econometric methods alone would not, however, have allowed to achieve a sufficient accuracy to provide recommendations about the cost-optimal insulation level.

From a methodological point of view, the main lesson learned from the research presented in this PhD thesis is that the economics of energy efficiency in the buildings sector is to be addressed by a

portfolio of methodological approaches that complement each other. To rely on only one methodological approach would have led to serious shortcomings.

6.2 Policy propositions

The findings and conclusions allow some policy-relevant suggestions. The following policy propositions are formulated based on the knowledge gained in this theses and related project-related research as well as on insights gained from the relevant literature and from interviews with companies, private and public stakeholders, and experts in the residential building sector. Although the analysis is not comprehensive with regard to exact design and the evaluation of the advantages, drawbacks, benefits and costs of possible policy options for achieving high efficiency gains in the residential building sector, the following short propositions illustrate the type of policy portfolio that is needed to take up simultaneously the existing obstacles efficiency improvement in residential buildings is presently facing.⁷¹

The favourable cost-effectiveness below or near economic viability, the flat character of the curve of the total annual costs as a function of increasing energy-efficiency and the expected dynamics towards lower marginal costs suggest that building codes should be tightened for new buildings on a regular basis (and for minimal requirements for any type of promotion measures). Even in the case of only moderate future energy prices, a more ambitious efficiency level would be at least as cost-effective as the current standards which actually correspond to a level of slight under-investment (cf. Chapter 2). This finding is particularly valid when looking at the asymmetric energy risk exposure of low insulation levels and at the very long re-investment cycles of the building envelop. A regular re-evaluation of building codes and technical standards is also important since induced techno-economic progress usually diffuses – with a certain time lag – to renovation practice of the existing buildings.

Although housing ventilation systems could not be evaluated to be profitable by energy cost savings alone, the willingness to pay approach resulted in a positive overall evaluation for a significant part of both tenants purchasers of single-family houses. Ventilation systems may also be justified from a societal welfare point of view (e.g. acceptable living conditions in streets with high traffic load). Given the novelty of this building component its promotion is still necessary, but does not necessarily have to include subsidies. Instead, policy measures could focus on adequate information dissemination, professional training, standardisation and quality control.⁷²

The observation of a significant experience curve effect justifies a (temporarily and declining) promotion of innovative components to reduce the gap between the costs of these measures and under-investment (less thickness of insulation or less efficient windows).⁷³ This dynamic would decisively be stimulated if advanced levels (e.g. according to the Minergie-Module level in

⁷¹ Some of the following recommendations may already be on the way of implementation on different levels, this to verify was not possible at the moment of their formulation, in these cases they would underpin these activities by the research results presented in this PhD thesis.

⁷² Such activities are being undertaken for instance by the association “energie-cluster” in Switzerland.

⁷³ The gap would even be narrowed if the progress ratio of the technology as such was the same, simply due to the difference in cost structure; the capital costs share of the average costs of heat generation is only to 30% to 40% and the marginal costs of heat generation are almost exclusively determined by fuel costs (which are expected to rise rather than to fall).

Switzerland) were gradually imposed by mandatory codes at the national (or Canton) level, supported by mandatory heat inspection certificates as presently imposed by the EU (EBPD, 2006).

From a policy design point of view the findings regarding the WTP for energy-efficient building attributes and regarding the decreasing costs as a function of the (cumulative) application of such measures are directly related: the high willingness to pay of certain segments by building owners (as first movers) can be used to “finance the experience curve”. However, it is presently unclear how large this group of first movers may be and how much it would “buy down the learning curve” of the innovative components in residential buildings.

Awareness raising

An indispensable step to enhancing energy efficiency levels is awareness rising within several target groups in the residential sector. Providing technical information in terms of brochures and other information material is useful, but not at all sufficient to raise awareness and to initiate action. A clear efficiency goal shared by most relevant stakeholders and communicated to relevant target groups is an essential pre-requisite for successful policy making. The efficiency goal should be well founded, plausible, and convey the co-benefits; it can be visionary in the long run, but should be achievable. Only if owners or investors are convinced about the potential benefits they are more likely to adopt energy efficiency modes. Energy-efficient buildings have not to be considered and marketed only on the basis of technical, energy efficiency or cost saving aspects, but as a comprehensive approach improving the overall quality of buildings, including architectural quality, aesthetics, housing comfort, value added and social prestige.

To raise awareness and stimulate motivation and the need for action, a broad public campaign may also be necessary. Such a campaign should comprehend the general public, similar to the campaigns of energy suppliers who have created a clear and long-lasting presence in the public (as demonstrated by sponsoring the national Ski team or the top soccer league or establishing the green leaf). It could involve well-known and broadly accepted personalities outside the energy sector. The real estate and housing sectors and its associations, the construction, building technology, and renovation sector could bundle their efforts and operate a joint platform. Parallel to the mentioned campaign, specific and timely information instruments such as labels and certificates (e.g. Energiepass, cf. Baumgartner et al., 2004; Rieder et al., 2006) should be created and promoted (see below).

Appraisal of total benefits (incl. co-benefits)

The economic valuation of the co-benefits of efficient components such as high quality windows, ventilation systems and facade insulations should receive more attention in professional training of architects, planners, and installers. The training material should clarify that energy efficient buildings provide high living comfort that also pays off economically due to the induced increase in the resale value of buildings or due to improved leasing potential (rental revenue). The arguments and figures about these qualitative and quantitative benefits should also be included in awareness campaigns and in other information measures such as labels and certificates.

Information and market transparency

It is not general information on efficient residential buildings that is missing, but specific, concise and easily understandable information at the moment of decision is lacking, leading to market intransparency and poor results. Market transparency is a pre-requisite to make use of the willingness to pay (WTP) for more energy efficient buildings. Market transparency could be achieved by a mandatory efficiency label scheme similar to the one now being implemented in all EU member

countries due to the EU Buildings Directive. Labelling allows for product differentiation by creating a common language between the different types of actors and stakeholders involved (owners, tenants, contractors, managers, and financiers). An ex-ante evaluation, as was made for household appliances (cf. Hammer et al., 2005), would be useful to check the response of the housing market and to design the label system effectively. Note finally that such a label system is quite useful for the effectiveness of other policy instruments such as fiscal incentives, White Certificates, or subsidies.

Building codes and technical standards

As the considerable techno-economic progress observed is mainly due to building codes and standards rather than due to economic incentives, stringent codes are justified as an instrument supporting the diffusion of innovative technologies, related knowledge. They also induce diffusion from the practise of new buildings to the renovation of existing buildings. Building codes and standards are technology push type policy measures. The current energy standards of Minergie for new buildings and of Minergie-Modules could be considered as candidates to be made mandatory.⁷⁴

Economic incentives

Reliable and long-term economic boundary conditions are important for three main reasons: (1) Cost-effectiveness of EE is not given in all cases, but it is sensitive and conditioned to some specific decision rules regarding interest rates and useful life time which might not be accepted in all sectors.⁷⁵ (2) Economic incentive schemes can be used to disseminate information⁷⁶ and to increase market transparency (e.g. energy certificates and energy audits for buildings). (3) Investing actors are ascertained with stable long-term boundary conditions, i.e. a reliable price signal.

There has been no in-depth analysis of suitable measure for economic incentives in the residential sector in this thesis, but a somewhat flexible CO₂-surcharge scheme maintaining a certain energy price level could be considered as one promising option given the Swiss CO₂ law and long term needs to curb CO₂ emissions of residential buildings. The revenues could be partly used for specific support of owners to affect their maintenance-overhauling-renovation decision process. Such a support should be conditioned to minimal EE requirements.

If fiscal incentives are adopted (instead or in addition), one interesting option is a tax credit scheme rather than a scheme of deductions from the taxable income. With a tax credit system the incentive is – at least in absolute terms - constant for all income groups which would overcome the drawback of the current fiscal incentives. Also, as opposed to the current tax system, future fiscal incentives should be related to minimal efficiency requirements.

⁷⁴ From an energy policy perspective and from the point of view of building owners and investors it is necessary to be far-sighted with regard to thermal insulation due to the long re-investment cycle of the building envelop of three to more than five decades. Due to increasing risks and necessities in the long run (climate change, depletion mid point of oil, and associated price risks) and due to the fact that it is substantially more expensive to reinforce thermal insulation on a later occasion (up to a factor of 3) it is evident to opt for advanced energy efficiency levels. Considering the risks of increasing energy prices, i.e. the probabilities and the potential impacts on heating costs, “over-investment” in thermal insulation can be understood as an insurance policy. To a later point in time this could include also the requirements regarding ventilation / air exchange

⁷⁵ Accordingly, economic considerations such as financial hurdles or lack of cost-effectiveness are cited by quite some owners as reasons having hindered energy efficient renovations

⁷⁶ Executives of subsidy programmes of Swiss Cantons report that such programmes raise awareness and lead to contacts and consulting opportunities.

Overcome split incentive structure

Rethinking of the incentive structure is needed in the case of rented flats in multi-family buildings. Due to the pass-through limitations of EE investments in the Swiss tenancy law and due to the fact that tenants benefit from energy cost savings, the cost-effectiveness of such measures is reduced as compared to the case of single-family house-owners. Hence, the pass-through limitations should be raised to a higher level. The issue of split incentives between owners and tenants could also partially be resolved by contracting or by splitting energy costs, although some legal boundary conditions would have to be adjusted.

Promote research, development, demonstration, innovation, and best practice

The external benefits of new and innovative technologies justify promotion of research, development and demonstration projects. The latter is particularly important; it serves to provide potential followers with the lessons learned from previous experiences. Hence, findings on such projects should be made public.

Portfolio approach

Finally, from the analysis of barriers and drivers (CHAPTER 5) it can be concluded that several factors often prevail simultaneously and that these factors are often interdependent. Therefore, a coherent portfolio of policy measures is essential for effectiveness of energy efficiency policies in residential buildings.

Monitor impact and success of policy instruments

The impact and the success of the policy instruments suggested above should be monitored on a regular (annual) basis. Such a monitoring could include the observation of the specific energy demand of a building sample and the observation of the renovation behaviour (annual rates of different modes, distinguishing between maintenance, overhauling and energy-efficient renovations). Such a monitoring could be realised by a revolving sample, drawn from the federal building and apartment register (GWR) which is being currently established.

6.3 Critical remarks and perspectives

The analysis presented in this PhD thesis is focused on economic aspects of the construction and refurbishment of residential buildings, complemented by an analysis of barriers and drivers of energy efficiency, the latter mainly from a building owner perspective. Although the research approach was quite broad, some shortcomings are worth addressing.

- The outcomes regarding the marginal costs of energy-efficiency investments and its potentials could be affected by the rebound effect, which could lower the assumed effect. This is due to lower (variable) energy costs which could, firstly lead to a more frequent and more intense use of energy-efficient technologies and or appliances and, secondly, to other types of expenditures which induce additional energy demand on their part. The first effect could have some relevance in the case of building envelope energy efficiency investments;⁷⁷ if the heating system is not

⁷⁷ The first effect has a significant relevance in the case of housing ventilation systems, since air exchange rates of mechanically ventilated buildings are usually higher than those in naturally ventilated buildings. Thus, parts of the savings gained with heat-recovery are compensated by the increased exchange rate. This was taken into account in the analyses of Jakob, Jochem et al. (2002) and Jakob (2006).

adjusted accordingly, the indoor temperature might be increased after building insulation. On the other hand users might lower the indoor temperature since insulated surfaces increase thermal comfort. The variable cost effect is presumably quite low since net cost savings are low; lower energy costs are almost exclusively compensated by increased capital costs.

- In the techno-economic analysis the transaction costs were not considered. Including these transaction costs (internal or external expenses for project definition, searching, information, tendering, and decision making), could affect the cost-effectiveness of EE investments considerably, particularly in the case of small investments (cf. Ostertag, 2003). In the case of EE building investments transaction costs are moderate in relative terms due to the high investment costs of such measures, but nevertheless not completely negligible (estimated to 5% to 15%).
- The trade-offs between preferences regarding building envelope investments and various other types of building investments (kitchen, bathroom, materials) or other types of investments or expenditures (vacation, cars, other consumer goods) were not specifically addressed. Such other (non-energy) housing projects may be more attractive (also economically) and are therefore a competition even to economically viable EE projects. Hence, such trade-offs could explain more precisely the observed renovation choices or EE levels in the case of new buildings.
- Structural and behavioural aspects of the construction and renovation market and the interests of architects, planners, installers and technology producers were only assessed to a limited extent, if at all; they may have a significant impact on the diffusion of EE in the building sector. For instance, there is much evidence that the competition of the mentioned companies is focused very much on low upfront cost rather than on life cycle costs and quality differentiation.

Hence, further research is not only needed on the technological level, but also on the socio-economic level. Although some insights could be gained by the research presented here, an economic model of renovation decisions and of new constructions is still lacking (e.g. the sensitivity regarding energy price increases or regarding technology price decreases or regarding incentive schemes such as labels, tax incentives, and others). Moreover, in view of the techno-economic progress, a regular update of the cost-benefit relations present in this PhD thesis would be a useful decision element of policy design. Finally, from a scientific point of view, further research is also needed regarding the appraisal of different policy options or sets of policy options.

First uses of the knowledge accumulated during the analysis for the PhD thesis

Results and outcomes have been used in several fields of application, independently and in collaboration with the author, including energy demand projections (Energy Perspectives of the Swiss Federal Office of Energy, Energy perspectives and CO₂-Reduction Potentials up to 2010, and electricity share of 2000 Watt society), energy policy adviser tools (CEPE-Energy Navigator for Switzerland and the city of Zurich, novatlantis ECO2-calculator of city of Zurich), policy consulting and design (Swiss federal building energy strategy, Vision 2050 of Canton of Zurich), the design of policy instruments (the actually implemented building energy efficiency promotion programme of the foundation “Klimarappen”), information brochure (Costs and benefits of thermal insulation of residential buildings), and building owner or investor advisory tools (WWF, optihouse).⁷⁸ Although

⁷⁸ BFE (2007), Jochem et al. (2007), Jochem, Jakob et al. (2004), Kost (2006), Meier and Ott (2005), Kessler et al. (2005), AWEL (2006), Jochem et al. (2006), Ott and Jakob (2006), Hofstetter and Jakob (2006), BFE (2003 and 2004), www.wwf.ch/heizen, www.optihause.ch

the analysis focused on residential buildings in Switzerland, many of the insights gained from this investigation can be taken up and adapted to other building sectors and countries.

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1994 – 2000 **Paul Scherrer Institut (PSI), Villigen, Switzerland**
Scientist in the Energy Systems Analysis Division, Energy Economics group and in the GaBE-Project (comprehensive assessment of energy systems) in the fields of energy economics and energy modelling.

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