THERMAL UPGRADES OF EXISTING HOMES IN GERMANY: THE BUILDING CODE, SUBSIDIES, AND ECONOMIC EFFICIENCY

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Abstract

One of the cheapest ways to save energy and reduce CO2 emissions is thermal renovation of existing homes. Germany is a world leader in this project, with a strict building code, generous state subsidies, and an advanced renovation infrastructure. The effects of its policies are here explored in the light of progressive tightening of the building code, and the strict criteria for subsidies. Data on costs and outcomes of residential building renovations are presented from published reports on renovation projects, and cross-checked with a small sample of projects investigated directly. Comparisons are made in terms of euros invested for every kilowatt-hour of heating energy saved over the lifetime of the renovations, for standards ranging from 150 (the lowest standard) to 15 (the highest) kilowatt-hours of primary energy use per square metre of floor area per year. It is found that the lowest standard is an order of magnitude more cost-effective than the highest, in terms of both energy saved per euro invested, and return on investment over the lifetime of the renovations, regardless of fuel prices. It is argued that this throws into question Germany's policy of progressively regulating for higher renovation standards, and offering subsidies only for projects that go beyond the minimum standard.

1. INTRODUCTION

Human activities in existing buildings are the cause of around 40% of the world's total primary[1] energy consumption (IEA, 2006). In the UK this figure is around 30% (Odyssee 2006), of which about half comes from space heating (TSO, 2006). In Germany, where average winter temperatures are some 3ºC lower than in Britain, space heating accounts for over 75% of household energy use (VDEW, 2000), and in the EU as a whole around 70% (EEA, 2005). Total energy used for home space heating in the EU is increasing, mainly due to the increasing number of households and larger size of dwellings (Enerdata, 2004).

Since much of this energy comes from fossil fuels, energy consumption by households is a very significant issue in attempts to reduce GHG emissions. It has been variously estimated that space heating in buildings accounts for some 25% of EU countries' GHG emissions, about half of which – around 12% - comes from households (de T'Serclaes, 2007). Since there is a direct relationship between GHG emissions from space heating, and energy used in space heating, this sector is contributing to the current steady increase in GHG emissions worldwide.

There is great potential for energy savings in household space heating (IEA, 2006; de T'Serclaes, 2007). Renovating a 1950s German apartment block to the pre-2004 'minimum' standard (see below) can cost less than 3 eurocents per kilowatt-hour (kWh) of primary energy saved over the lifetime of the renovations (Enseling and Hinz, 2006). This compares to the much higher costs of generating energy from renewables such as wind power (8 cents) and photovoltaics (28 cents), and the spot-price of electricity (7 cents), or current heating oil costs (6 cents) (Galvin, 2009; Großklos et al., 2008). Refitting homes can, if planned sensibly, be one of the world's cheapest ways to save energy and reduce GHG emissions.

Of course, this does not take into account subsequent changes in energy use patterns due to the rebound effect (Khazzoom, 1980; Sorrell and Dimitropoulos, 2008; Ruzzenenti and Basosi, 2008). For example, in their study of recent home heating upgrades in Britain, Milne

[1] 'Primary' household energy consumption includes the energy lost through transportation of useful energy to households. 'End-use' energy refers only to energy consumed usefully in the household.

and Boardman (2000) found that upgrading can form a justification to consume more fuel, even though this costs more, because now the householder is getting better value for money. Hence the uncertainties due to human behaviour changes after thermal refits and other energy efficiency measures offer a caution of the necessarily tentative nature of the findings of studies such as this.

The remainder of this introductory section outlines the relevant issues in the German building code, and how they relate to thermal renovation (TR) of existing homes (EHs) as compared to new builds. It also outlines the system of state subsidies for TR. Section 2 examines case studies of TR projects, developing a mathematical model for comparing the fuel saving economics of various TR standards. Section 3 draws out the implications of this for policy development and incentives. Section 4 looks at counter-arguments, while conclusions are developed in Section 5.

1.1 The German Building Code

At the time of writing (August 2009) the rules for building renovations in Germany were given in the *Energieeinsparverordnung für Gebäude* 2007 (EnEV 2007, 'Energy Saving Regulations for Buildings'). This is a successor to EnEV 2004, and is supplanted again in September 2009 by EnEV 2009 (see VÄEV, 2009). The government has announced its intention of supplanting this once more in 2012 (BUNR, 2007).

A crucial point that must be understood at the outset is that EnEV 2004, 2007 and 2009 are designed primarily for new builds, not renovations. They set down the standards of thermal retention which must be achieved in new building design and construction. These standards are driven by the government's commitment to reduce energy consumption in buildings, but are carefully negotiated with the construction industry to take account of its current and future capabilities, so that optimally energy-efficient new buildings can be constructed for reasonable costs – i.e. they must, the legislation declares, be *'wirtschaftlich'* ('economic').

The new regulations (EnEV 2009) raise the standards for whole-building heat retention 'by 30%'. This means that the maximum permitted heat energy consumption per unit floor area is reduced to 70% of that permitted by EnEV 2007. In 2012 it will be reduced again, to 70% of the EnEV 2009 value, i.e. 49% of the EnEV 2007 value. EnEV 2007 did not upgrade the previous standard, but used the standard set down in EnEV 2004, with minor changes. However EnEV 2004 was a 30% upgrade on the previous standards.

Simultaneously, EnEV 2009 raises the standards for the average heat retention coefficient of a building's outer shell by 15%. This means that the maximum permissible 'U-values' (see below) are reduced to 85% of the EnEV 2007 values. Again, EnEV 2004 was a 15% upgrade on the pre-2004 U-value standards, and these will be raised by a further 15% in 2012.

The core of EnEV 2007 is its 'Table 1', an English translation of which is presented in Appendix 1. This sets out the maximum permissible primary energy use for space heating and the heating of drinkable water in a new home, using two measures, corresponding to the two parameters outlined above, each of which must be adhered to. One is 'Q_P', the maximum permissible primary energy use per kilowatt hour per square metre of floor area per year (kWh/m^2a). The other, 'H_T', is the maximum permissible heat transmission loss through the outer surface of the building (i.e. the average U-value), measured in Watts per square metre of building envelope per degree Kelvin (W/m^2K). These figures have to be worked out on the basis of keeping an all-round indoor temperature greater than 19°C[2].

Further, there is not one absolute figure for each of these two measures. Rather, there is a range given in the table, according to factors calculated from the shape and size of the building. This is because (a) larger buildings retain heat more easily than smaller buildings, as they have a smaller ratio of surface area to volume; and (b) cube-shaped buildings retain heat better than oblong or irregular-shaped buildings, as they, too, have a smaller surface area to

[2] To be strictly accurate, the rules only apply to residential buildings that are heated for more than 4 months of the year. For example, summer houses are not covered by this part of the building code.

volume ratio. The range of values in the table makes allowance for the difficulties of retaining heat in smaller or odd-shaped buildings – yet is nevertheless designed so as to incentivise the construction of the thermo-geometrically more efficient, larger, cubic-shaped buildings.

All this is modified by one further factor: local climate. To work out whether a building will comply with the heat retention rules one has to know the average local temperature. This must be worked out from a further table, in which Germany is divided into 348 postcode districts, each centred on a particular weather station (BVBS, 2007).

Hence, for new builds, EnEV 2007 is an accomplishment of creditable technical sophistication, while the step to EnEV 2009 moves thermal retention requirements for new builds forward.

Questions arise, however, in that the rules for renovating *existing* buildings are based directly on Table 1, which is designed for *new* builds. A mitigating factor – found in EnEV 2004, 2007 and 2009 - is 'the 40% provision': thermal retention standards of renovations of existing buildings are allowed to be 40% more lax than those of new builds. Numerically, this means that Q_P for renovations can be up to 1.4 times Q_P for new builds of corresponding shape and size.

For buildings renovated from 2004 to September 2009, this means that Q_P for renovations of most buildings has to be in the range110-160 kWh/m^{2}a, depending on size and shape of building. As from September 2009 this range becomes 75-110 kWh/m^{2}a. If the government's intentions for the 2012 adjustments are realised, the range will become 50-75 kWh/m^{2}a. Appendix 2 shows calculations of Q_P for a small and a large residential building, in each case both for new build and renovation standards.

1.2 New builds and thermal renovation
There are three peculiarities which arise through tying the rules for TR to those for new builds. Firstly, there are no guarantees that thermal renovation technology will advance in parallel to new build thermal technology. Many thermal features of old buildings are extremely expensive to change, such as orientation to the sun, size of windows, geometric shape, and thermal bridges.
Secondly, the mathematics of energy saving is different for new builds compared to renovations. Before a new building is erected on a vacant lot, the vacant lot is using no heating energy and causing zero GHG emissions. Hence the thermal success of a new build may be measured in direct proportion to how small its annual heating energy is, and how low its consequent GHG emissions are.

But energy use in existing buildings has a different profile. The buildings are already consuming energy and causing GHG emissions. Hence the crucial figure is the *reduction* in energy consumption through renovation, not its *absolute* value. Reducing the energy consumption of a building from, say, 300 kWh/m^{2}a to 40 kWh/m^{2}a is only 13% better than reducing it to 80 kWh/m^{2}a, even though the absolute values after renovation are in the ratio 1:2.

Therefore in this physically, mathematically obdurate way, thermal renovation differs radically from new builds. With renovations, the mathematics suggests that tightening the standards and increasing cost does not bring a proportionate gain in energy saving.

Thirdly, new builds cause a large 'pulse' of GHG emissions, due to the extraction and processing of heavy building materials, their manufacture and transportation to the building site, and the energy consumed in erecting the building (Power, 2008). These 'embedded' GHG emissions have been estimated to be equivalent to about 50 tonnes of CO2 for a typical 3 bedroom house (EHA 2008). Thermal renovation produces a much smaller pulse, as there are few heavy materials and much less work involved. This means that, even if a new building uses hardly any energy over its lifetime, it still takes 25-50 years before it starts to pay its way in comparison to an old building modestly renovated so as to reduce its emissions by 1 or 2 tonnes of CO2 per year. So building a new building *always* causes a jump in GHG emissions whereas TR *always* causes a reduction, a case could be made for forming much stricter thermal retention regulations for new builds than for TR.

1.3 Subsidies

The main state subsidies for thermal renovation are awarded only to projects carried out to higher standards (lower Q_P and H_T values) than the minimum requirements of the EnEV. The federal government's subsidy institution is the *Kreditanstalt für Wiederaufbau* (KfW; http://www.kfw-foerderbank.de)[3], which offers grants, and loans at subsidised interest, to renovators of residential properties[4]. However, the KfW does not recognise the '40% provision', so its loans are only given to renovation projects which achieve the new-build Table 1 levels. Further, an even lower interest rate and higher grant are offered to projects which achieve levels 30% stricter than the regulations. The best interest rate, then, can only be had for projects attaining 50-75 kWh/m^{2}a. If this policy is continued as from September 2009, this level will tighten to 35-50 kWh/m^{2}a.

Other state subsidies are available from some local authorities. Munich City Council, for example, offers grants for residential projects which achieve the standard of 40 kWh/m^{2}a for Q_P and which also surpass the EnEV's highest H_T standard[5] (Munich, 2009), proudly calling this *'Der Münchner Standard'.* Freiburg, too, offers grants, based on the achievement of specific thermal resistance levels for walls, windows, attics, etc., that go beyond minimum standards (Freiburg, 2009).

Hence, there is pressure to tighten standards for thermal renovation, both in the progressive development of the building code, and in the state subsidies available for renovation projects.

2. COSTS AND OUTCOMES OF RESIDENTIAL BULDING RENOVATIONS

Buildings come in all shapes and sizes and are renovated to various thermal standards, so it is not easy to compare costs and outcomes accurately. In general, case studies of recently renovated residential buildings reveal that the stricter the standard, the higher the cost, not just of the renovations as a whole, but of the energy saved per euro invested. As we shall see, this latter figure can be as low as 3 eurocents per kWh of saved energy for a building renovated to 193 kWh/m^{2}a, rising to around 20 cents for renovations to 40 kWh/m^{2}a, and 40 cents or more for the *'Passivhaus'* standard of 15 kWh/m^{2}a (Passivhaus Institut, 2008). These figures depend on several assumptions, such as the expected life of the renovations; whether discount rates are used to calculate future benefits arising from fuel saving; what the energy consumption of the building was prior to renovation; and what expenses are counted as relevant to the renovations. The latter question arises because there are always 'anyway'[6] costs which would have to be borne regardless of what thermal standard is aimed for. Further, often when one renovates, one also adds extras – such as a new balcony or an extra window – the costs of which should not be counted as part of the thermal renovation.

With regard to energy consumption prior to renovation, this varies wildly (Schuler, et al., 2000), and examples cited in the German Energy Agency's database range from 200 to 450 kWh/m^{2}a (DENA, 2009).

A further question concerns the way we add up the energy saved through renovating, since this accrues throughout the lifetime of the renovations' efficacy. To begin with, we have to make an intelligent guess as to this lifetime. Typically this is assumed to be 25 years (e.g.

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[3] Usually known in English as the 'German Development Bank'.

[4] The rules for these loans were updated in April, 2009 and are summarised at (http://www.energiefoerderung.info/).

[5] The rule is H_T max = (1 – 45%) x (0,3 + 0,15 / (A/V_e)) in W/(m²K); e.g. for a house with A/V_e = 0.6, this is 0.4125, which is stricter than the strictest H'_T in the Energieeinsparverordnung (EnEV) 2007. A/V_e is a factor worked out from the dimensional propereties of the building.

[6] The Germans speak of *'sowieso'* costs, translated here as 'anyway' costs, for want of a known standard terminology.

Enseling and Hinz, 2006), though some studies estimate different lifetimes for different aspects of the renovation (e.g. Jakob, 2006; Großklos, 2008). Secondly, we need to decide how to value energy saved in future years, compared to that saved today. A building of 80 m^2 floor area which, through renovation, has its energy consumption reduced by 100 kWh/m^2a, will save 8000 kWh per year, or a total of 200,000 kWh over 25 years. Is a saving of 8,000 kWh in 25 years time more, less, or equally valuable as a saving of 8,000 kWh today? Is it better, worse, or equally valuable to save a tonne of CO2 emissions today as in 25 years time? Perhaps the need to reduce CO2 emissions is so urgent today that current reductions count more than later reductions.

Since we are comparing various TR scenarios here, the crucial thing is to treat future CO2 savings in a consistent way between cases. I will avoid discounting future energy savings but make reference to authors who do.

Finally, in comparing various TR projects I will use the dimension 'cost of saving each unit of energy consumption', in euros or eurocents per kilowatt hour (€/kWh or eurocents/kWh).

2.1 Ludwigshafen Renovation Project

Enseling and Hinz (2006) examined the outcome of a large thermal renovation project in Ludwigshafen[7], undertaken from 2000 to 2003 by the home-building and renovation firm LUWOGE (http://www.luwoge.de/). An aging 1930s subdivision of 850 apartments was renovated to a range of thermal standards, using techniques aimed at producing 150 kWh/m^2a, 70 kWh/m^2a, 40 kWh/m^2a and 30 kWh/m^2a apartment blocks. The relevant building regulations at the time were prior to those of EnEV 2004, when the minimum standard was closer to 150 kWh/m^2a for medium-large sized buildings, than the EnEV 2004 and 2007 standard of around 110 kWh/m^2a.

Enseling and Hinz used 150 sensors to monitor the performance of the apartments after renovation, measuring temperature, humidity and air quality, together with fuel usage. In general they found 'exceptionally high air quality and a high level of comfort in the apartments' (p.7). They also noted that, on average, residents set heating controls to maintain an air temperature of 22°C.

This study is extremely useful because it is a large sample (850 dwellings) of very similar apartments, restored after war damage in one integrated project, and finally thermally renovated in another integrated project by one firm, to a range of specifically chosen thermal standards

Enseling and Hinz set their data alongside that of a theoretical substandard model, 'render[8]', in which the weatherproofing of the buildings is renewed but no extra work for thermal improvement is undertaken. The study notes that the average heat energy usage before renovation was 275 kWh/m^2a.

In constrast to EnEV 2007, Enseling and Hinz use 'end-use energy' rather than 'primary energy' as their measuring stick. However, the difference is minor with regard to heating oil (in contrast to electric heating), and in any case does not affect comparisons between various standards.

The authors' summary of energy end use, and cost of renovation, for each of the 5 standards is given (in English translation) in Table A[9]. We note that the lowest standard achieved in the project was 193 kWh/m^2a, somewhat below the 2007 'minimum' standard of 150 kWh/m^2a.

[7] There are two cities in Germany named Ludwigshafen. The one referred to here is across the Rhein from Mannheim. The other is further south, on the shores of Lake Constance.

[8] A 'render' is a layer of weather-resistant material coated on the outside wall to protect its surface. If external wall insulation is used, the render covers and protects the insulation layer.

[9] Entitled Table A so as to avoid confusion with 'Table 1' in EnEV 2007 and EnEV 2009.

Standard	Measures taken	Energy end-use (kWh/m^2a)	Total costs (€/m^2 of floor area)	Costs of energy-saving measures (€/m^2 of floor area)
Render	External wall render only	275	40	0
193 kWh/m^2a	8 cm external wall insulation	193	76	36 **= 36**
70 kWh/m^2a	20 cm external wall insulation 8 cm cellar ceiling insulation 14 cm insulation between spars Double-glazing (U_w-1.1W/m^2K) Simple ventilation system	70	87 15 17 50 28 **=** **197**	47 15 17 15 28 **=** **122**
40 kWh/m^2a	20 cm external wall insulation 8 cm cellar ceiling insulation 14 cm insulation between spars Double-glazing (U_w-1.1W/m^2K) Heat-exchanger ventilation system	42	87 15 17 50 93 **=** **262**	47 15 17 15 93 **=** **187**
30 kWh/m^2a	20 cm external wall insulation 20 cm cellar ceiling insulation 14 cm insulation between spars 6 cm insulation over spars Triple-glazing (U_w-0.8W/m^2K) Heat-exchanger ventilation system Special measures to prevent heat bridges	28	87 20 17 6 94 93 72 **=** **389**	47 20 17 6 59 93 72 **=** **314**

Table A. Energy end-use, total costs and energy-saving cost measures for the 5 standards of thermal upgrade of homes in Ludwigshafen. Translated from Enseling and Hinz (2006: 11)

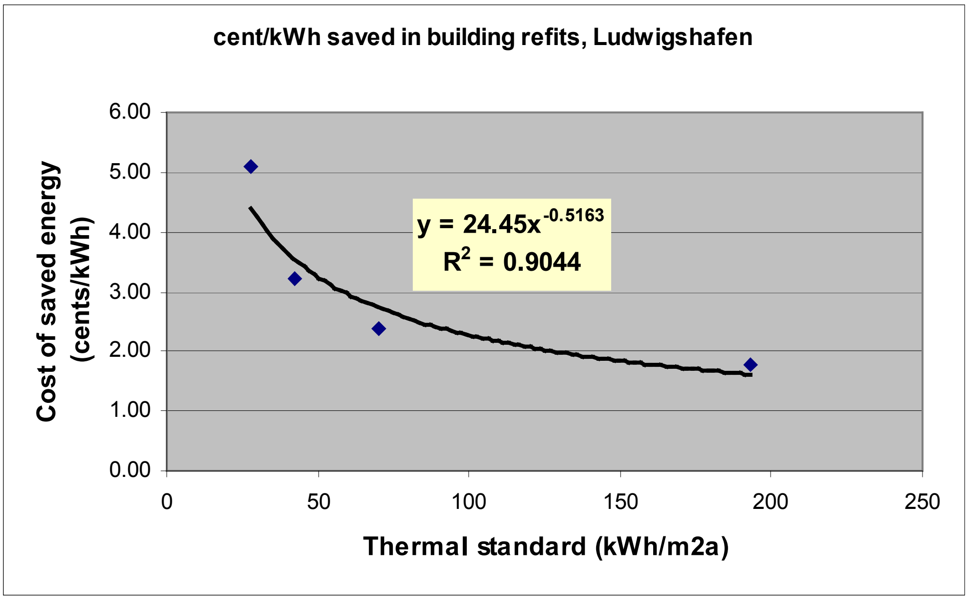
Table A shows that the costs of thermal renovation per square metre of floor space (€/m^2) ranged from €36 for the lowest standard, of 193 kWh/m^2a, to 314 €/m^2 for the highest standard achieved in the project, namely 28 kWh/m^2a. On the surface this seems to be a large difference, but by themselves these figures are not decisive, as the 30 kWh/m^2a standard clearly saves more energy and fuel than the 193 kWh/m^2a standard.

We therefore need to calculate the expected energy savings for each standard, assuming a 25 year lifespan for the efficacy of the renovations. Our results are given in Table B. Enseling and Hinz's results are also given, and these are higher as they discount future energy savings. It will be seen, however, that the proportions between the various standards are identical.

Standard	Cost of energy saved (€/kWh) – without discounting future energy savings	Cost of energy saved (€/kWh) – Enseling and Hinz's (2006) model
193 kWh/m^{2}a	0.0176	0.0299
70 kWh/m^{2}a	0.0238	0.0420
42 kWh/m^{2}a	0.0321	0.0567
28 kWh/m^{2}a	0.0509	0.0926

Table B: Cost of each kilowatt hour of energy saved (€/kWh) over a 25 year lifespan of the renovations. Own model compared with that of Enseling and Hinz (2006: 15) Ab. 4.1.

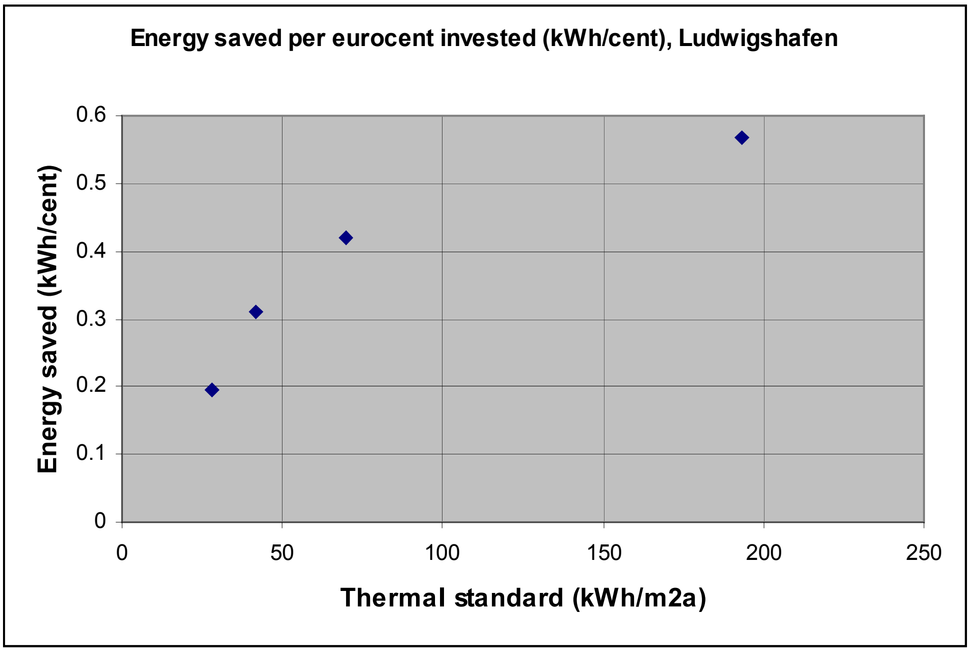
Here we see the superior economic efficiency of the lower standard, compared to higher standards. Each kWh of energy saved by the lowest standard cost just under 1.8 cents, while this price rose to 2.4 cents for the 70 kWh/m^{2}a standard, 3.2 cents for the 42 kWh/m^{2}a standard, and just over 5 cents for the 28 kWh/m^{2}a standard. While more energy is saved *per building* when renovating to a higher standard, more energy is saved *per euro invested* when renovating to the lower standard. This trend is clearly identifiable in the display of these results in Graph 1.



Graph 1. Costs of energy saved over the lifetime of renovations in the Ludwigshafen study. Data source: Enseling and Hinz (2006).

The graph shows the cost of energy saved rising rapidly as the standard is tightened (moving toward the left on the graph). Using the power function: $y = 24.45x^{-0.5163}$ a high correlation ($r^2 = 0.9044$) was found. The trend line is not to be relied on too heavily for extrapolation to tighter standards, as these often require qualitatively different technologies, with step-wise increases in cost.

The reciprocal of this graph is also useful (see Graph 2), as it displays energy saved per eurocent as a function of thermal standard. Moving to the left of the graph, we see that tighter thermal renovation standards save progressively less energy per eurocent invested.



Graph 2. Energy saved per eurocent invested, over the lifetime of renovations in the Ludwigshafen study. Data source: Enseling and Hinz (2006).

The depth of these curves is reduced, however, if the 'anyway' costs (e.g. weatherproofing the wall exterior with render) are counted as part of the thermal renovation costs. As the last 2 columns in Table A indicate, Enseling and Hinz excluded these costs from their calculation of cents/kWh of energy saved (displayed in Table B). This is fair, in that a house can be repaired without thermal improvements. However most apartment blocks in Germany are not in need of render repair but are candidates for thermal renovation. In these cases the 'anyway' costs should be counted. Including these costs for the Ludwigshafen estate increases the cost of energy saved to 3.71, 3.84, 4.50 and 6.30 cents/kWh for the 193, 70, 42 and 28 kWh/m^{2}a cases respectively. The trend is still clear, but is not so sharp:
Now $y = 12.242x^{-0.2423}$; and $r^2 = 0.698$.

2.2 A Comprehensive Swiss Study

The Ludwigshafen study is useful because it enables fair comparisons to be made based on a large number of very similar apartment buildings, purposefully renovated to a range of standards, all by the same firm. It could be argued, however, that this local, homogeneous focus also limits its broader applicability.

A far more comprehensive analysis is provided by Jakob (2006). While this refers to renovations in Switzerland rather than Germany, it is useful for comparative purposes because weather conditions, building infrastructure and building codes are similar in the two countries (though costs differ). Jakob brings together the actual costs of a large representative sample of thermal renovations of existing homes during the decade 1993-2003. In contrast to Enseling and Hinz, who monitored the actual thermal performance of dwellings post-renovation, Jakob estimates performance using standardised thermal transmission values for the various techniques and standards of thermal renovation undertaken. Further, Jakob uses the measure of marginal, rather than absolute, costs. This enables him to make meaningful comparisons without knowing the pre-renovation energy consumption of the buildings.

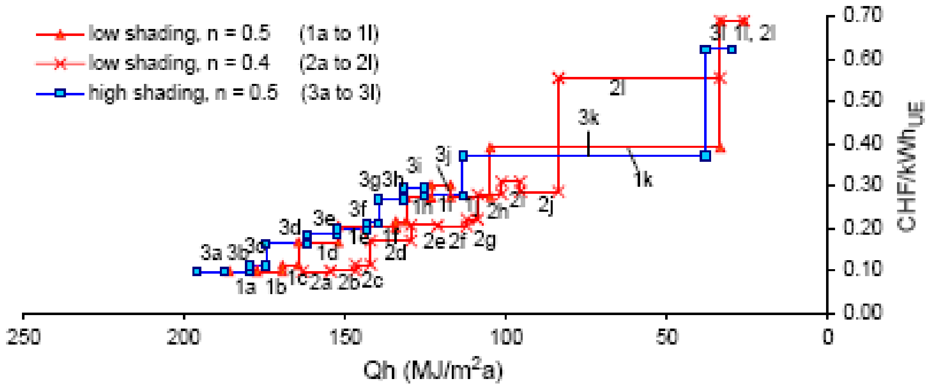
Jakob quantifies the marginal costs of energy efficiency investments, for each increment in the standard of refurbishments above a specified baseline. His baseline is a dwelling that consumes 300 MJ/m^{2}a (equal to 83 kWh/m^{2}a[10]) of 'useful' (end use) energy per year. His most stringent standard is the Swiss *Minergie* (Minergie, 2008), which consumes 50 MJ/m^{2}a

[10] 1 kWh = 3.56 MJ.

(14 kWh/m²a) and is the equivalent of the German *Passivhaus* standard (there were no homes of this standard in Enseling and Hinz's study). On the other hand, Jakob does not consider the equivalent of the German 'minimum' standard, of 150kWh/m²a.

Unlike Enseling and Hinz, Jakob assumes differentiated lifetimes for various aspects of the renovations: 50 years for roof insulation, 40 for wall insulation, 30 for windows, and 15 for ventilation systems. Using these estimates he amortises renovation costs for each element over its own lifetime and combines these into an annualised cost. Further, he considers both the average costs of each standard of renovations, and the 'best practice' (i.e. least expensive) costs, for each element of renovation.

Jakob shows that marginal costs of thermal renovation, in terms of Swiss Francs (CHF) invested per kWh of energy saved, rise along with the standard of renovation. This data is displayed in Graph 3.



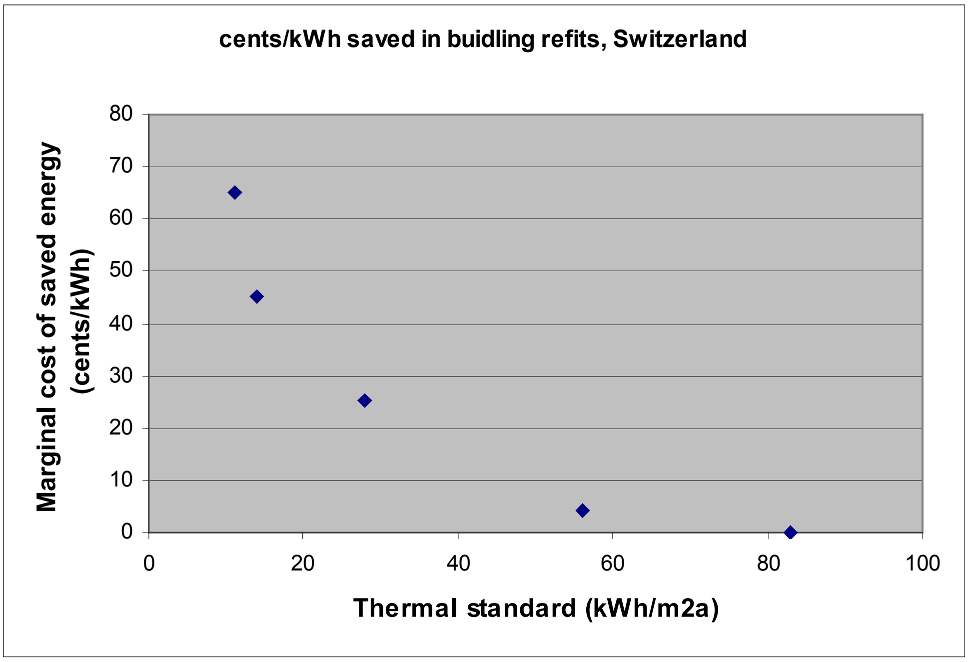
Graph 3. Average marginal costs of a range of standards of thermal renovation of dwellings in Switzerland, using a consumption of 83 kWh/m²a of useful energy as a base. Source: Jacobs (2006: 181).

To compare these figures with those of Enseling and Hinz, it is useful to translate Swiss francs into euros, and MJ into kWh. The Swiss study focuses on the four standards of 83, 56, 28 and 14 kWh/m²a (= 300, 200, 100 and 50 MJ/m²a). Graph 3 shows that the difference (margin) between renovating to 83 and 56 kWh/m²a is around 0.1 CHF per kWh of energy saved (approximately €0.05). The next step, to 28 kWh/m²a has a marginal cost of 0.25 CHF (€0.125). The next, to 14, has a marginal cost of 0.45 CHF (€0.225). There are also some examples of even higher standards, such as 30 MJ/m²a (= 11 kWh/m²a), which has a marginal cost of around CHF 0.65, or €0.325).

Since these are marginal and not absolute costs, we cannot work out actual costs of energy saved from his data. However the marginal cost results resonate with Enseling and Hinz's data as they show a steady increase in costs *per unit of energy saved*, as the standard of renovation increases. These figures are displayed in Table C and Graph 4.

Standard	**Marginal cost per unit energy saved, compared to baseline of 83 kWh/m²a (€/kWh)**
56 kWh/m²a	0.05
28 kWh/m²a	0.25
14 kWh/m²a (Passivhaus/Miergie)	0.45
11 kWh/m²a	0.65

Table C. Marginal costs of various standards of thermal renovation of large sample of homes in Switzerland. Source: Jakob (2006), based on data p.181.



Graph 4. Eurocents invested per kWh of energy saved, above reference case, in large sample of residential building refits in Switzerland. Data source: Jakob (2006).

We note the similar shapes of Graphs 1 and 4. The margins are much higher, however, in the Swiss study than in the Ludwigshafen project. Jakob's increase in cost from 56 to 28 kWh/m^{2}a (20 cents) is almost 8 times as high as Enseling and Hinz's increase of 2.6 cents/kWh from 70 to 28 kWh/m^{2}a. The figures also show that costs rise even further for higher standards, with a jump of 20 cents/kWh from the 28 kWh/m^{2}a standard to the Passivhaus standard of 14 kWh/m^{2}a, and further 20 cent/kWh jump to achieve the relatively small extra saving of 3 more kWh/m^{2}a.

Despite the more expensive Swiss marginal costs overall, we can confidently conclude that the trend revealed in the Ludwigshafen study becomes something of a general rule when applied to a very large sample of renovations. The higher the standard, the higher the cost, not only of the actual renovations but, more important, in terms of money invested per unit of energy saved.

2.3 Other Recent Cases

The German Federal Energy Agency, DENA *(Deutsche Energie-Agentur),* has an online database of 'best-practice' building renovation projects[11]. 'Best-practice' here means buildings renovated to higher thermal standards than those demanded by the current building regulations. The database includes measures of before-and-after primary energy use, floor area, age of building and date of renovations, but does not give the costs of renovations. However, several architects and renovation firms whose work is represented in the database generously provided costing information for this study.

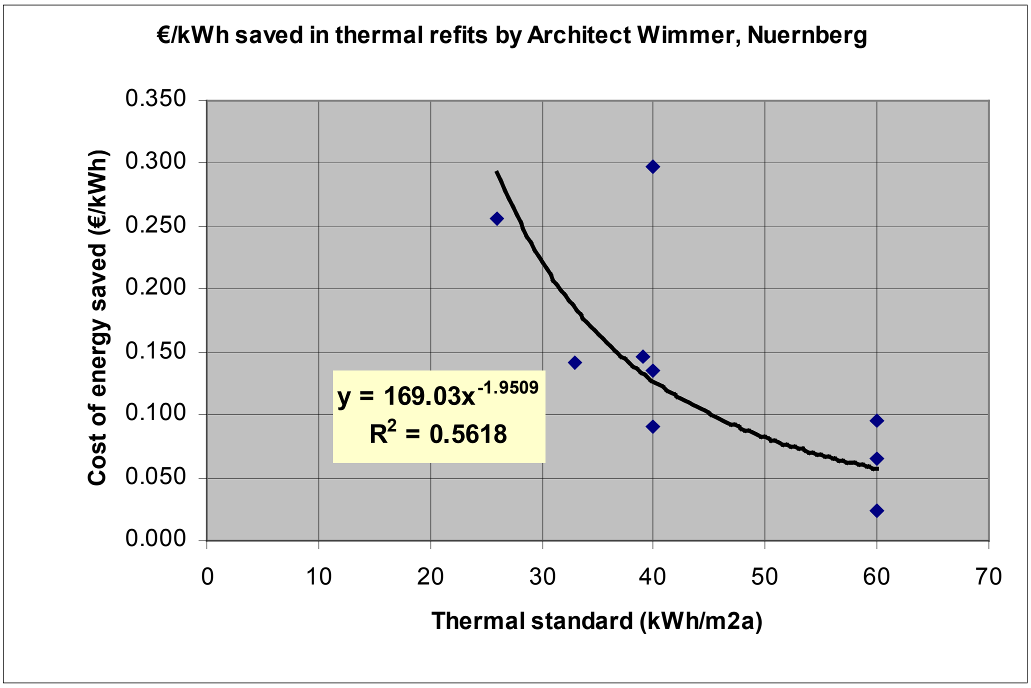
Architect Benjamin Wimmer, of Nürnberg, provided 10 cases. This data is here analysed assuming a 25 year life for the efficacy of the renovations, and with no discount rate. The data, with calculated results in bold type, is given in Table D.

[11] http://www.zukunft-haus.info/de/projekte/niedrigenergiehaus-im-bestand/best-practice-datenbank.html

Case No.	Year built	Year reno-vated	floor area (m2)	cost (€)	initial energy use (kWh/m2a)	energy use after refit (kWh/m2a)	**cost/m2 (€/m2)**	**cost/m2a (€/m2a)**	**energy saved (kWh/m2a)**	**€/kWh saved**
1	1930	2002	200	154000	250	33	**770**	**30.800**	**217**	**0.142**
2	1940	2006	117	90000	250	39	**769**	**30.769**	**211**	**0.146**
3	1980	2007	161	76000	250	40	**472**	**18.882**	**210**	**0.090**
4	1950	2006	695	215000	250	60	**309**	**12.374**	**190**	**0.065**
5		2006	130	186000	250	26	**1431**	**57.231**	**224**	**0.255**
6	1950	2006	155	70000	250	60	**452**	**18.065**	**190**	**0.095**
7	1950	2006	170	120000	250	40	**706**	**28.235**	**210**	**0.134**
8	1960	2006	160	250000	250	40	**1563**	**62.500**	**210**	**0.298**
9	1950	2006	575	64000	250	60	**111**	**4.452**	**190**	**0.023**
10		2007	467	370000	250	40	**792**	**31.692**	**210**	**0.151**

Table D. Thermal renovation examples from architect Benjamin Wimmer, Nürnberg.

These results, for euros invested per unit of energy saved over the lifetime of the renovations, are plotted in Graph 5. Again the stricter standards of renovation are represented on the left hand end of the Graph, with the lower standards on the right.



Graph 5. €/kWh saved, in building refits by Architect Wimmer, Nuernberg

Though there is wide variation in the costs of energy saved (€/kWh), and the sample is small, the trend line with the highest correlation (r^2 = 0.5618) is again a power function, as in the Ludwigshafen study. Renovating to the 60 kWh/m^{2}a standard costs about 6.5 cents per kWh of energy saved, while this rises to 21 cents for the stricter standard of 30 kWh/m^{2}a. These figures are about double those in the Ludwigshafen study but follow the same general trend. Without the outlier, case No. 8, the correlation coefficient r^2 rises to 0.6626.

A further set of examples was provided by architect Helmut Ertmer, of Freiburg. This consisted of two adjacent apartment blocks of identical age and similar style, but different floor areas. Data and calculations for these are given in Table E.

Case No.	Year built	Year reno-vated	floor area (m2)	cost (€)	initial energy use (kWh/m2a)	energy use after refit (kWh/m2a)	**cost/m2 (€/m2)**	**cost/m2a (€/m2a)**	**energy saved (kWh/m2a)**	**€/kWh saved**
11	1961	2005	1564	1300000	288	59	**831**	**33.248**	**229**	**0.145**
12	1961	2005	1173	1478000	292	39	**1260**	**50.401**	**253**	**0.199**

Table E. Thermal renovation examples from architect Helmut Ertmer, of Freiburg.

A difficulty with this data set is that the costs, as displayed, include (unknown) 'anyway' costs, so that the actual renovation costs were lower than listed. This suppresses the proportionate difference in thermal renovation costs. Nevertheless, it is again clear that renovating to a higher standard results in higher costs per unit of energy saved: 14.5 cents for the 59 kWh/m^{2}a standard, rising to 19.9 cents for the stricter, 39 kWh/m^{2}a standard.

A further example, provided by the Main-Tauber Kreisbau (Building society), gave a result of 12 cents per kWh of saved energy for renovation to a standard of 45 kWh/m^{2}a. While there was no similar case for local comparison, it accords well with the Nürnberg results, adding to the evidence that renovating to high thermal standards results in relatively high costs of energy saved.

To conclude this section, there is overwhelming evidence that the cost of energy saved rises sharply and steadily with increasing strictness of thermal renovation standards. Renovating to the pre-EnEV 2004 minimum standard for renovations can be as cheap as 1.8 eurocents per kWh of end-use energy, though this 'starting figure' may well be higher with some architects and builders and if 'anyway' costs are counted. Costs rise exponentially for stricter standards. It is probably fair to say that energy saved through Munich's minimum standard of 40 kWh/m^{2}a would cost about twice as much per kWh as energy saved through renovation to the minimum standard by a comparable firm. Renovating to 30 kWh/m^{2}a costs about three times as much, while costs for standards above that tend to double for every 10 kWh/m^{2}a tightening in the standard. Meanwhile, energy saved through renovating to the Passivhaus standard of 15 kWh/m2a costs 6 or 7 times as much as energy saved through the minimum standard.

3. IMPLICATIONS FOR POLICY AND INCENTIVES

There is a wide range of circumstances under which residential buildings may be thermally renovated, each of which carries its own peculiarities of funding. Three scenarios will be considered here: a municipality renovating its social housing; the effect of state subsidies in enabling private homeowners to renovate; and cost thresholds for low income home owners.

3.1 A Municipality Renovating its Social Housing

Many German municipalities own thousands of social dwellings, most of which are old and expensive to heat. Municipalities have limited funds to renovate these, so they need to do the work in stages, as money comes to hand. Hence, no matter what standard they renovate to, there will always be more dwellings waiting to be renovated. Further, all the money so invested is public funds.

In such a situation the economically efficient thing to do is save the largest amount of energy with the funds that are available. This means, quite simply, that all dwellings should be renovated to the minimum standard. Renovating to a higher standard will save more energy per dwelling renovated, but will save less energy overall. This is because of the large amounts of energy being consumed by the dwellings that were not renovated, but could have been, if the money had not all been spent on renovating just a few dwellings to a higher standard.

This also has implications for the German building code. As from September 2009, when EnEV 2009 takes effect, the 2007 minimum standard of around 110 kWh/m^{2}a will no longer be permissible. Raising the standard by 30% will raise the cost per unit of energy saved, and therefore a municipality's money will save less energy. This can be roughly quantified using the formula[12] in Graph 1. Here:

$Y = 24.45 \times X^{-0.5163}$, where

Y = cost of saved energy, in eurocents per kWh, and

X = thermal renovation standard, in kWh/m^{2}a.

Raising X by 30% (as in EnEV 2004) increases Y by 20%: i.e. tightening the building code by 30% will increase the cost of saving 1 kWh of energy by around 20%. EnEV 2009 increased it by a further 20%, or 44% compared to the pre-2004 standard.

If the federal government's plan to raise the standards by a further 30% in 2012 is fulfilled, the cost of energy saved will rise by a further 20%, or 74% compared to the pre-2004 standard.

Further, the Munich standard, of 40 kWh/m^{2}a, results in a cost of energy saved which is 98% higher than that of the pre-2004 minimum standard. If Munich renovates its social housing to this standard it gets only half the possible value for its money. In practice the costs are likely to be much higher still, as the Ludwigshafen project, on which these figures are based, enjoyed considerable economies of scale in what was essentially mass-production of TR.

The same issues apply to private landlords who own large residential portfolios. Their renovation programmes, where they have them, will become progressively less economically efficient in terms of energy saved per euro invested.

3.2 The Effect of State Subsidies

In general the same principles apply to the use of state subsidies for renovation, whether these come through grants or reduced interest loans. The KfW's demand that all renovation projects must match the standards for new builds (i.e. 33.3% stricter than the minimum standard[13]) has the effect of a 20% increase in the cost of energy saved. Its more generous subsidies, for renovation projects consuming only 70% of the minimum standard for new builds, results in a 44% increase in the cost of energy saved. Hence this public money is being used non-optimally.

It could be argued, however, that setting the subsidies at these levels encourages homeowners to renovate to high standards, and when they do so, the bulk of the money is paid by the homeowners, not the state. Hence a small state subsidy goes a long way.

This argument raises two issues. Firstly, the question as to how many homeowners would renovate if the standard demanded is high, low, or middling is an empirical question, which has not been investigated. It could be the case that, if subsidies were available for the much cheaper renovations at the minimum standard, far more people would renovate and even more private funds would be invested in energy saving. Whether or not this is so is unknown.

Secondly, those who do renovate to the stricter standards are spending their own money inefficiently in terms of energy saved per euro invested. Looking at the examples from architect Benjamin Wimmer, above, any renovations to a higher standard than 60 kWh/m^{2}a takes the cost per kWh saved well above the cost of, say, generating energy by wind power. Again, however, we do not know what these people would spend their saved money on if they renovated to a lower standard. There is probably little harm done in a few individuals spending small fortunes renovating old homes (see the amounts in Table D, column 5: the highest is €370,000), but if this occurred on a mass scale, questions would need to be asked about the wisdom of so much of Germany's money going into economically inefficient ways of

[12] This formula should not be generalised to all cases, as costs depend on a range of variables. However its general shape gives a broad indication of comparative costs of energy saved for various TR standards.

[13] The building code allows thermal refits to consume 40% more energy per square metre than the standard for new builds. Denying this right results in a 33.3% increase, since 140% less 33.3% of 140% = 100%.

energy saving while far more efficient avenues are available.

3.3 Cost Thresholds for Low Income Homeowners

An important factor in decisions as to whether or not to thermally renovate a home has to do with what may be called the 'cost threshold'. This is the minimum amount of money a homeowner has to spend, to do any thermal renovation at all. If this threshold is too high for the homeowner's budget, no renovations can be done. Pre- EnEV 2004, this threshold was set at an affordable level. Even if most renovation projects were twice as expensive as the Ludwigshafen project, the homeowners in a block of flats, each with about 90 m^2 of floor area, could renovate the block to the 150 kWh/m^2a standard for around €6,000 each. Since a huge proportion of the German population lives in such dwellings, keeping to these standards could move forward the project of thermal renovation of existing homes in Germany persistently and steadily.

However, raising the minimum standard by 30% raised the cost threshold by around 100%, since this is the absolute cost of renovations, not the cost per kWh of energy saved (see, for example, the right-hand column in Table A). A further 30% tightening of standards in EnEV 2009 will raise it by another 100%, i.e. to four times the pre-2004 cost. For the same reasons, the pressure from municipalities such as Munich and Freiburg, to persuade people that the minimum standard is not good enough, can deter would-be renovators before they start.

4. COUNTER-ARGUMENTS

Because of the general rule that the stricter the standard of thermal renovation the lower the economic efficiency, it has been argued here that it makes good economic sense to renovate to lower standards rather than high standards. But several counter-arguments are vigorously put forward against this. These concern rising fuel prices, resale value of a home, and rent value.

4.1 Rising fuel prices

It is frequently argued that stricter renovations are justified by the fuel costs they will save, as fuel prices rise in future years. In their study of the Ludwigshafen project (above), Enseling and Hinz (2006) develop 3 scenarios for the price of end-use heating energy over the next 25 years. Starting with 5 eurocents per kWh in 2006, they consider annual price increases of 3%, 4% and 5% above an assumed rate of inflation of 2.5%. This gives an average fuel price per kWh, over 25 years, of 7, 8 and 9 eurocents respectively. Hence, they conclude, the most stringent standard in their study (28kWh/m^2a) becomes economic for the higher rate of increases in the price of energy, i.e. when both fuel price, and cost of renovation, equal 9 eurocents per kWh. In further calculations they show that an annual fuel price increase of 4% above the rate of inflation would lift the average energy price to 9 eurocents if the starting price is 5.8, rather than 5, eurocents. They further note that if the renovations had a 30 year lifespan the 28kWh/m^2a standard would become economical if the annual increase in energy price were only 4%, with a starting price of 5 eurocents per kWh.

There are two difficulties with this approach. Firstly, it shifts focus away from the fact that the lower standards still do better than the higher as fuel prices rise, at least for credible fuel price scenarios. My own modelling, based on Enseling and Hinz's data, shows that the fuel price would have to average 70 eurocents per kWh over the next 25 years – about 12 times the value in May 2009 – to make the highest standard become the *most* profitable.

Secondly, it gets the arithmetic wrong at a more fundamental level. In a large project we cannot simply compare the fuel savings of one expensively renovated block with those of one cheaply renovated block of the same size. Instead we have to compare the yield on two investments of equal monetary value – a million euros invested in strict renovations, compared to a million invested in lower-standard renovations. When we do this, the lower standard wins every time, no matter how high or low the fuel price is, because each euro invested in lower-standard renovations brings fuel savings several times as large as a euro invested in stricter standard renovations.

Jakob (2006) makes the same error in his economic assessment of Swiss renovations. Even given this error, however, the high cost of renovations in Switzerland lead him to conclude that the highest standard is not profitable under foreseeable circumstances.

The same approach is taken by Großklos et al. (2008) in their study of renovations of three very similar, adjacent blocks of two apartments each, in Hofheim, each to a different thermal standard (Großklos et al., 2008). These standards were 108 kWh/m^{2}a, 60 kWh/m^{2}a, and 40 kWh/m^{2}a. The authors calculate expected costs and benefits using an inflation rate of 2%, an annual energy prise rise of 5% and a starting gas price of 6.5 eurocents per kWh. From this they conclude that the building renovated to the lowest standard of the three will bring a return of €278, while the middle standard brings an annual return of €1, and the highest an annual loss of €290. This result, too, is flawed, as it fails to account for the fact that far less money was invested in the lower standard – hence their approach tends to diminish the lowest standard's profitability in relation to the higher standards[14].

The important points here are that higher standards seldom, if ever, match lower standards for profitability in scenarios reflecting credible fuel price increases, and even if they did, in terms of a return on investment (profit per euro invested) the lower standard always wins because it saves more fuel per euro invested.

4.2 Resale value

Jakob (2006: 182ff) develops further arguments in support of stricter standards, though admitting they are not directly profitable. Chiefly, he argues that the extra money is well invested because it lifts the resale value of the property. Citing Borsani and Salvi (2003), he notes that energy efficient windows can lift property value by 2-3.5%, and suitable buyers will pay a 9% premium (standard deviation 5%) for the *Minergie* standard of 14 kWh/m^{2}a. Thermal renovations can also insulate against noise; ventilation systems improve indoor air quality; and a steady indoor temperature makes for improved comfort. These factors, plus lower fuel consumption, enable such homes to command higher resale prices.

There is merit in these arguments but they carry two main flaws. Firstly, as Jakob's own data shows, the resale return can be well below the investment cost. A 9% premium for a *Minergie* standard home is woefully small compared to the cost of renovating to this standard - which can be well over 50% of the original property value. There is copious anecdotal evidence that homeowners who have renovated to high thermal standards lose out badly on reselling their property, though it would take further research to confirm and quantify this.

Secondly, it is erroneous to compare the resale price increase of one home expensively renovated to high thermal standards, with the resale price increase of one home inexpensively renovated to the minimum standard. Where less is invested, of course less will be returned. Instead, we should compare the proportionate increase in value compared to the amount of money invested. This will almost invariably result in a greater return, euro for euro, with the lower standard, simply because, as this study has shown, it gives greater fuel saving for the money invested.

4.3 Rental value

Jakobs uses similar arguments to make a case for landlords renovating to high thermal standards. If they do, he says, they can charge more rent.

This argument runs into the same difficulties as the resale arguments. Further, it makes assumptions about landlord-tenant relationships which are difficult to support. Landlords cannot automatically demand more rent to cover renovation costs if the tenancy agreement does not allow for this, and if landlords are renting anew they can only charge what

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[14] The authors make a further error, in their attempt to show that the higher standards would have out-performed the lower standard if the ventilation systems installed in the two higher standard buildings were treated as 'anyway' costs (pp. 150-151). They subtract the cost of a basic ventilator from the higher two standards, but fail to subtract an equivalent amount from the lower standard. When this error is corrected, the differences between the annual profits of the three standards becomes equal to that in the case which treated the ventilators as part of the thermal improvements.

prospective tenants can pay. Further, and ironically, new rental laws in Germany will favour lower-standard renovation rather than higher. Under these laws, a tenant can demand a rent reduction if the property consumes more fuel than the corresponding EnEV standard, in proportion to the excess. A sensible landlord will therefore renovate to an optimum level, where the best balance is achieved between cost of renovations and loss of rent. Since the highest return on investment, in terms of energy saved per euro invested, comes at the lower end of the standards, a frugal landlord would keep to that end.

5. CONCLUSIONS AND RECOMMENDATIONS

There is, roughly, an inverse power law relationship between the amount of money invested in thermal renovation and the amount of energy saved per euro. Costs of renovating to standards above 60 or 70 kWh/m^{2}a rise exponentially while the amount of energy saved rises only a very small amount. For a house that previously consumed 300 kWh/m^{2}a of heating energy, there is hardly any difference in energy saved between reducing this by 240 kWh/m^{2}a, to the 60 kWh/m^{2}a standard, and reducing it by 270 kWh/m^{2}a, to the 30 kWh/m^{2}a standard (a 12.5% difference in energy saved), but the costs per unit of energy saved can differ by over 100%.

Most attempts to justify renovations to the higher standards do so on grounds of higher absolute return, and thereby make a common error: they fail to consider the heating fuel consumed by the buildings that were *not* renovated, but could have been, if all the money had not been spent on the one building that was renovated to a very high standard.

There is huge potential for thermal renovation, to a minimum or modest standard, among Germany's millions of flat-façade apartment blocks. This could be achieved very cheaply in terms of euros invested per kilowatt hours of energy saved. It would more than pay for itself, provided the chosen standard of renovation were to keep this cost below the price of heating fuel, currently about 6 cents per kilowatt hour.

This opportunity will be lost when the minimum standard for thermal renovation is pushed 30% above its EnEV 2007 level. It will double the cost threshold, making it unaffordable to many private homeowners and landlords. It will also reduce the return on investment in terms of energy saved per euro invested.

In light of these findings the following recommendations are made for policy makers and for further research.

5.1 Recommendations for policymakers

Firstly, the legislation upgrading the building code for thermal renovation of existing buildings (VÄEV, 2009) needs to be modified so that renovation of these buildings will not have to conform to a standard 30% stricter than that permitted by EnEV 2007. This can be achieved by changing the phrase *'nicht mehr als 40 vom Hundert',* in VÄEV 2009: § 9. B 2., to *'nicht mehr als 100 vom Hundert'.* With this change, renovators would use the new 2009 'Table 1', but could overrun its figures by 100%, which is equivalent to overrunning the 2007 Table 1 by 40%.

Legislators must then revisit this issue when finalizing plans for further tightening of the building regulations in 2012.

Secondly, the KfW needs to broaden its loan criteria to include renovation projects that conform to the 40% provision in EnEV 2007. This will ensure that state-subsidised loans are available for the projects that save the most energy per euro invested, and thereby result in a more effective use of state funding. It will also make low income people more able to renovate their homes and reap the benefits of improved comfort and lower fuel bills.

Thirdly, municipalities such as Munich and Freiburg need to lift the restrictions on their grants to thermal renovation projects, making them available to all who plan to renovate within the law. Again, this will result in a far more effective use of public funds, and make benefits more accessible to low income homeowners.

Fourthly, municipalities and states need to cease their practice of seeking to persuade homeowners to renovate above the minimum standard.

Fifthly, municipalities need to cease the practice of renovating social housing to stricter standards than the minimum. This spends public money non-optimally, while denying or delaying thermal comforts to thousands of tenants.

5.2 Recommendations for further research

Firstly, there needs to be research on the effect of 'cost threshold' (see 3.3 above) on the likelihood of renovation being undertaken. If and when the minimum standard for renovation is tightened by 30%, this threshold will increase by over 100%, and a further 100% for a further 30% tightening. We need to find out the extent to which this will put renovation beyond the reach of increasing numbers of people.

Secondly, there needs to be research on how much private money public subsidies could cause to be spent on renovations if these subsidies were made available for projects at the minimum standard. There is an assumption that, by offering incentives only for strict-standard projects, this causes the greatest amount of private money to be spent on energy saving. However there is no evidence in support of this. It may be completely erroneous. Perhaps there would be a flood of renovations if subsidies were offered at the low end of the market. We do not yet know.

Thirdly, there needs to be research on the resale value of properties which have been thermally renovated, particularly in terms of value recouped in proportion to moneys invested.

Finally, there needs to be social science research on why the current subsidy, regulatory and promotional characteristics of thermal renovation of existing homes in Germany are the way they are. Why is it that subsidies are so inappropriately directed, in terms of achieving their stated goal of saving energy? Why is the KfW out of step with EnEV minimum standards? Why are such expensive but cost-ineffective projects so consistently praised, while inexpensive, extremely cost-effective projects are not only looked down upon, but are being legislated into non-existence? These are fascinating questions. If they could be answered, perhaps ways could be found of redirecting the German home renovation project onto a more fruitful and cost-effective path.

Appendix 1. Permissible levels of space heating energy end-use and heat transmission loss for new builds in EnEV 2007 (English translation by the author)

Table 1. Permissible levels of space heating energy end-use and heat transmission loss for new builds. (Author's translation of EnEV 2007: 2.3.1.1)

Relationship A/V_e	Annual energy end-use		Specific heat transmission loss in relation to the heat envelope
	Q_p'' in kWh/(m²·a) according to building use area		H'_T in W/(m²·K)
	Residential buildings (apart from those in Division 3)	Residential buildings with predominantly electrical water heating	All residential buildings
1	**2**	**3**	**4**
≤ 0.2	66.00 + ΔQ_{TW}	83.80	1.05
0.3	73.53 + ΔQ_{TW}	91.33	0.80
0.4	81.06 + ΔQ_{TW}	98.86	0.68
0.5	88.58 + ΔQ_{TW}	106.39	0.60
0.6	96.11 + ΔQ_{TW}	113.91	0.55
0.7	103.64 + ΔQ_{TW}	121.44	0.51
0.8	111.17 + ΔQ_{TW}	128.97	0.49
0.9	118.70 + ΔQ_{TW}	136.50	0.47
1	126.23 + ΔQ_{TW}	144.03	0.45
≥ 1.05	130.00 + ΔQ_{TW}	147.79	0,44

$$\Delta Q_{TW} = \frac{2600 \, \mathrm{kWh}/\mathrm{a}}{100\mathrm{m}^2 + A_N} \quad \text{in kWh/(m²·a)}$$

V_e is the total heated volume of the building. If, for example, the basement and the loft are not heated, they are not counted in V_e.

A is the total surface area that encloses V_e. This includes the outside walls, the floor of the bottom (heated) storey and the ceiling of the top (heated) torey.

$A_N = 0.32\ V_e$. (The figure 0.32 is the reciprocal of the height, in metres, of one storey in a high-ceilinged building. Hence A_N is the floor area of a building of heated volume V_e with a floor-to-ceiling height of 1/0.32, i.e about 3.125 metres, or 10ft 2".)

Appendix 2. Calculating the required thermal standards for two types of residential building under EnEV 2007

Using 'Table 1' of EnEV 2007 (Appendix 1), the required thermal standards for a small and a large residential building, for both a new build and a renovation of an existing building, are calculated below. To simplify matters it is assumed that the roofs of the buildings are flat, and that basements, if they exist, are not heated.

Case 1: A pair of two-storey semi-detached homes.

(a) New build:

Dimensions:
Floor area of each home: 75 m^2; Walls of each floor: 3m high
Outside dimensions of each home: 5m x 7.5m.

➔ Volume of block, $\mathbf{V_e}$ = 2 x 5m x 7.5m x (2 x 3m) = 450 m^3

Total floor area, $\mathbf{A_V}$ = 2 x 2 x 5m x 7.5m = 150 m^2

Total area of building shell,
A = 2 x 2 x 5m x 7.5m + 2 x 2 x 3m x 5m + 2 x 2 x 3m x 7.5m = 300 m^2

➔ $\mathbf{A_N}$ = 0.32 V_e = 144 m^2

➔ $\mathbf{\Delta Q_{TW}}$ = 2600 / (100 + 144) = **10.7**

A/V_e = 300/450 = **0.67**

➔ (from Table 1) $\mathbf{Q_P}$ = 100 + 10.7 = **110.7 kWh/m²a**

(b) Renovation of an existing building:

$\mathbf{Q_P}$ (renovation) = 1.4 x Q_P (new build)
= 1.4 x 110.7
= **155 kWh/m²a**

Case 2: A five-storey apartment block of 20 apartments.

(a) New build:

Dimensions:
Floor area of each home: 75 m^2 ; Walls of each floor: 3m high
Outside dimensions of total block: 10m x 30m

➔ Volume of block, $\mathbf{V_e}$ = 10m x 30 x (5 x 3m) = 4500m^3

Total floor area, $\mathbf{A_V}$ = 5 x 10m x 30m = 1500 m^2

Total area of building shell,
A = 2 x 10m x 30 m + 2 x 5 x 3m x 10m + 2 x 5 x 3m x 30m = 1800m^2

➔ $\mathbf{A_N}$ = 0.32 V_e = 1440m^2

➔ $\mathbf{\Delta Q_{TW}}$ = 2600 / (100 + 1440) = **1.7**

A/V_e = 1800/4500 = **0.4**

➔ (from Table 1) $\mathbf{Q_P}$ = 81.06 + 1.7 = **81.67 kWh/m²a**

(b) Renovation of an existing building:
$\mathbf{Q_P}$ (renovation) = 1.4 x Q_P (new build) = 1.4 x 81.67 = **114 kWh/m²a**

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