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AGENCE INTERNATIONALE DE L'ENERGIE

HIGH-RISE REFURBISHMENT

The energy-efficient upgrade of multi-story residences in the European Union

IEA INFORMATION PAPER

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EXECUTIVE SUMMARY

Some 36 million European households are in high-rise residences, one in six of all households, and yet many of the buildings are in urgent need of refurbishment. This study, which is one in a series being conducted on behalf of the International Energy Agency addressing the energy performance of the existing IEA-wide building stock, identifies a Europe-wide cost-effective energy saving potential of 28% from energy-efficient refurbishment of the high-rise residential building stock. Attainment of this potential would imply a 1.5% reduction of Europe's total final energy demand and annual CO_2 emissions savings of 35 Mt. In practice only the less efficient buildings need to be refurbished to realise these stock-average savings and for these buildings typical savings in heating energy from refurbishment of between 70 and 80% are identified.

Buildings in general suffer from a variety of barriers that tend to prevent their occupants from maintaining and refurbishing them to levels of comfort and energy performance that would be justified over the longer term, but collective housing in general is particularly susceptible to market failures. Many occupants do not own the property while their landlords usually have little motivation to finance improvements. Refurbishment requires collective agreement on a capital investment, which is difficult to establish especially when some occupants expect to live in the building over the longer-term but others only for the short-term. Furthermore, in most cases the occupants of high-rise residences are not among the wealthier members of society and they find it difficult to raise capital for longer-term investments. It is not surprising, then, to find that this section of the building stock is the most neglected and that there remain significant cost-effective opportunities for it to be refurbished in a way that improves comfort, saves energy, reduces CO_2 emissions and significantly improves the urban environment.

Figure I:
Base Regions

This research project, funded by the International Energy Agency and EuroACE (the European Alliance of Companies for Energy Efficiency in Buildings), investigates the potential for energy savings in high-rise residential buildings in Europe – defined by the 3rd European Housing Ministers' Conference on Sustainable Housing, in Genval, Belgium in 2002, as multi-family buildings with more than four storeys. It advocates the incorporation of energy efficiency improvements into widely needed overall refurbishment as a central element of sustainable refurbishment. The 28 countries covered by the project were organised into eight groups, according to socio-economic category ('old' EU members (EU15), 'new' (EU10) and accession (AS3) states) and climate as shown in Figure I and Table I.

Table I:
Categorisation of Countries

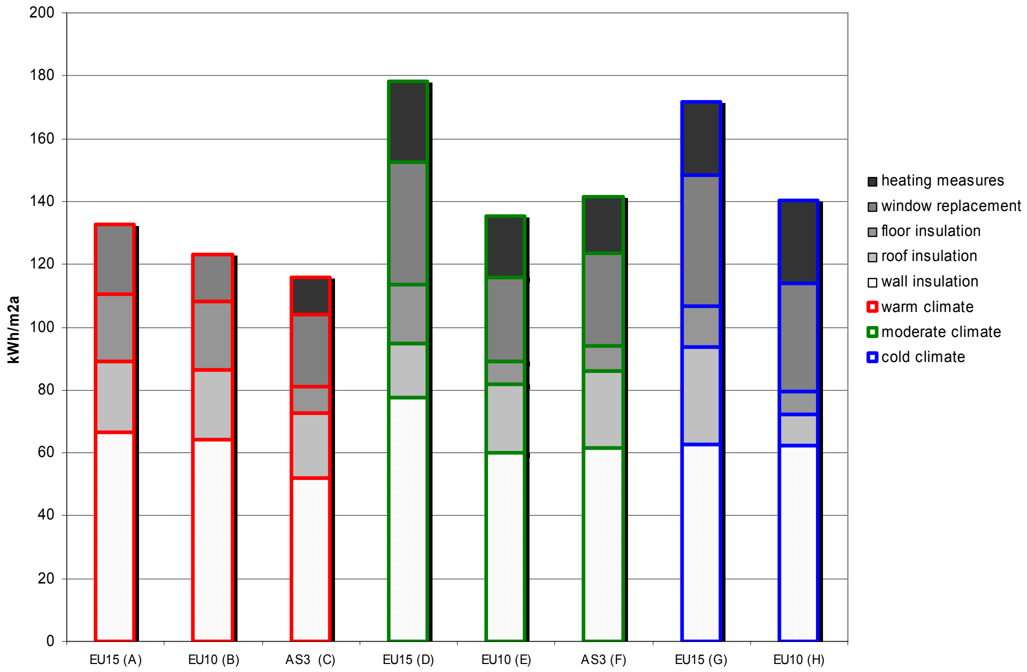
	EU15	EU10	AS3
Warm climate	France, Greece, Italy, Portugal, Spain (A)	Cyprus, Malta (B)	Turkey (C)
Moderate climate	Belgium, Ireland, Luxembourg, Netherlands, United Kingdom (D)	Czech Republic, Hungary, Slovakia, Slovenia (E)	Bulgaria, Romania (F)
Cold climate	Austria, Denmark, Finland, Germany, Sweden (G)	Estonia, Latvia, Lithuania, Poland (H)	-

Not all possible energy efficiency improvements were considered quantitatively. The quantitative assessment incorporated wall, roof and floor insulation, window replacement, and improvements to the heating system – all in terms of their effect on reducing heating demand. Many other measures, including external solar shading, the effect of insulation on reducing cooling energy demand, passive solar design, ventilation strategies, the reduction of internal heat loads and lighting play an important role in reducing energy demand in high-rise buildings, but fell outside of the scope of the quantitative assessment examining the cost-effectiveness and amount of energy and CO_2 savings.

ASSESSING THE SITUATION – FINDINGS FOR INDIVIDUAL BASE BUILDINGS

Using data from a variety of European surveys and based on expert knowledge, it was possible to create eight representative (of those in need of refurbishment) high-rise buildings with construction and energy features typical for buildings in each group of countries. The main findings from modelling the chosen measures in these *individual* 'base buildings' are shown in Figure II through to Figure V, covering a range of key indicators.[1]

Figure II:
Reduction of Heating Demand – Contribution of all Modelled Measures



- Achievable energy savings are substantial, ranging from approximately 70% to 80% of heating demand.

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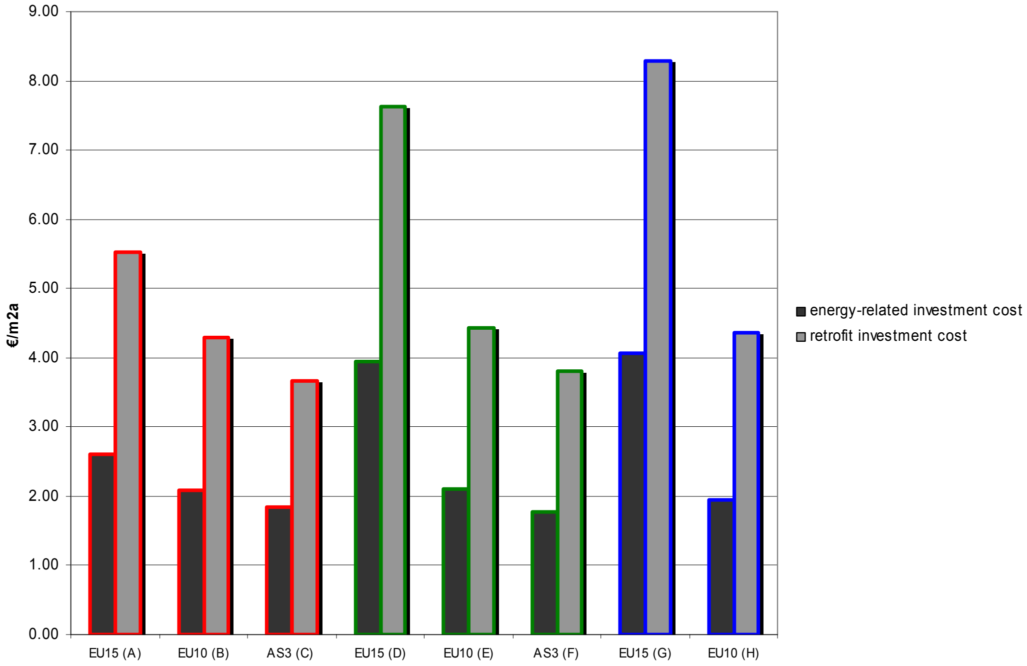
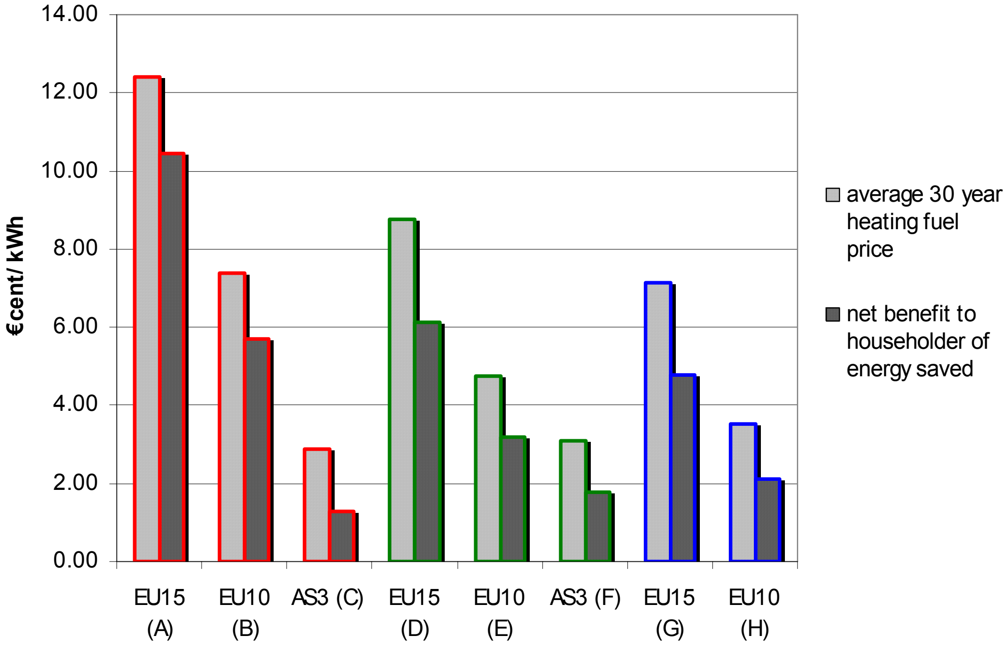
[1] Exact quantities of the findings, corresponding to Figures 2 to 5 are to be found in Annex 3.

Figure III:
Energy-Related and Retrofit Investment Cost



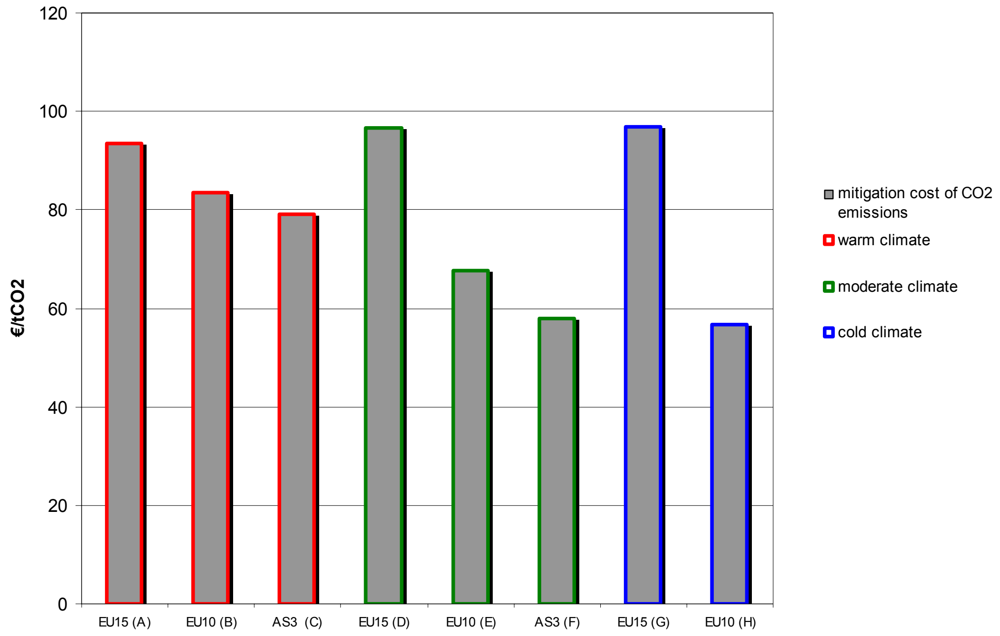
- The energy-related investment cost – i.e. the additional cost of making refurbishment that needs to take place anyway as energy efficient as is reasonably practicable – is approximately half what it would cost to improve energy efficiency separately from general refurbishment (i.e. 'retrofit').
- The cost of energy efficiency investment is lowest in EU10 and AS3 countries.

Figure IV:
Energy Prices and Household Benefit of Energy Saved



- Energy prices are (still) much higher in EU15 countries than in EU10 and AS3 countries.
- Taking reduced energy expenditure for households into account, there is a net benefit as a result of investment for all base buildings; the net benefits are highest in EU15 countries.

Figure V:
CO_2 Mitigation Cost

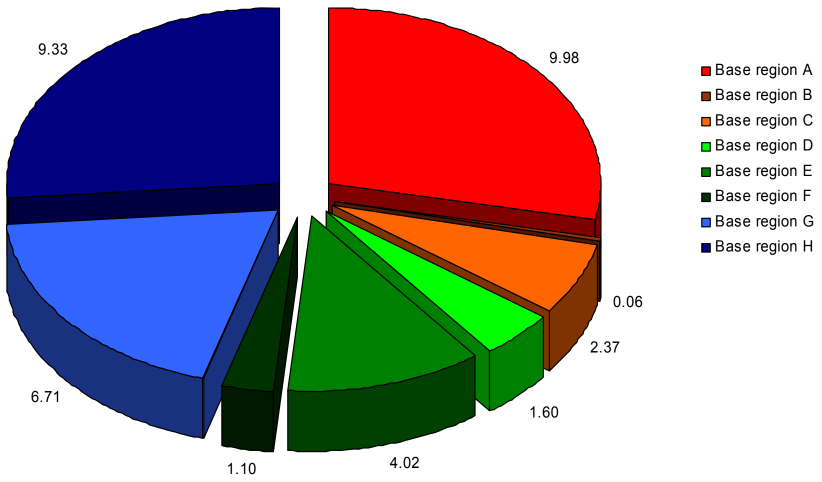


- *Net* CO_2 mitigation costs (i.e. after taking reduced household energy expenditure into account) are lowest in EU15 countries; more importantly, from a policy-maker's perspective, *gross* CO_2 mitigation costs, illustrated in Figure 5, are lowest in EU10 and AS3 countries.

ASSESSING THE SITUATION – FINDINGS FOR THE HIGH-RISE STOCK

With respect to overall CO_2 emissions there is scope for substantial reductions from the entire European high-rise building *stock*; this assessment, unlike the results presented so far, is *not* based on the modelling of individual base buildings, but on a survey of European Housing Ministries about their stock. Figure VI illustrates the annual CO_2 savings possible from the high-rise stock according to the Ministries surveyed, based on their estimates of energy saving potential.

Figure VI:
CO_2 Savings Potential according to National Housing Ministries [$MtCO_2$]



The highest energy saving potential is in Eastern Europe; 39% in base region E and 34% in base region H. Europe-wide, the energy saving potential is 28%, implying a reduction of Europe's total final energy demand of 1.5%, and a corresponding approximate emissions reduction of 35 $MtCO_2$. The lower stock-wide energy saving potential compared to the potential in individual base buildings (see Figure) is because it is assumed that each base building can be refurbished with respect to every energy efficiency measure considered, an assumption that holds true for many buildings, but of course not across the whole of a country's or region's high-rise stock.

In addition to the financial payback and reduced CO_2 emissions, the less tangible benefits of improved energy security (in terms of avoided investment in energy generation and distribution, increased system reliability, resource conservation and enhanced energy price stability), employment gains and improved resident comfort and wellbeing also need to be balanced against the required energy efficiency investment cost.

Six case studies, covering the various climatic and socio-economic regions and carried out as part of this project, highlight many practical approaches for appropriating the benefits outlined above, and carry a number of their own findings. Short summaries can be found in this report, and the full case studies can be downloaded on the project website at www.euroace.org/highrise. For the energy efficiency in the refurbishment of high-rise buildings overall, the main recommendations for policy are as follows.

FINDING A WAY FORWARD

Having identified that there are substantial benefits associated with improving the energy efficiency of high-rise residential buildings, in practice the realisation of the significant energy and emissions saving potential is faced with a number of institutional, economic, legal and social barriers, but also opportunities. A comprehensive assessment identified the following as significant, needing to be addressed or exploited:

Politically and Institutionally,

- the capacity to gain an accurate picture of the state of high-rise buildings, to administer financial instruments and ensure best practice is applied in the refurbishment of the high-rise stock is crucial. A number of important European projects, notably OPET Building, SUREURO, LOCOSOC and the project underlying this paper can contribute to filling gaps in knowledge and know-how;
- rapid privatisation and the much higher proportion of privately owned housing in EU10 and AS3 countries poses specific, but not exclusively, institutional challenges to refurbishment, requiring new approaches and partnerships. Public private partnership approaches to refurbishment could hold much promise, though experience is thin on the ground.

Financially and Economically,

- energy prices are a key determinant of the attractiveness of energy efficiency investment; with the lowest European prices likely to rise more rapidly than others, the incentive to save energy should strengthen; the target groups of new and existing financial instruments to promote energy efficiency in high-rise buildings would become more receptive to them. In this context, there is an important opportunity in the extensive European body of knowledge surrounding the design and implementation of effective financial instruments;
- flat-rate tariffs associated with district heating provision in EU10 and AS3 countries in particular, so common in the high-rise stock, pose a significant barrier in that they do not create any incentive on the part of the householder to save energy and thus undermine the effectiveness of grants and subsidies. In these cases, creating the right framework for district heating suppliers to provide a full energy service may supply another means by which to improve high-rise energy efficiency;
- financial incentives designed to link to the Energy Performance of Buildings Directive’s (EPBD) certification requirements – and to the Energy End-use Efficiency and Energy Services Directive (ESD) – present a powerful opportunity to strengthen the case for incorporating energy efficiency improvement into refurbishment;

- the effect of the economic cycle and interest rates on housing expenditure and competing priorities for investment – in particular for public funds – serve to highlight the fact that most investment in high-rise buildings is needed where least is forthcoming, mainly in EU10 and AS3 countries.

Legally,

- the EPBD's January 2006 transposition deadline offers a central legal opportunity to drive the improvement of high-rise energy efficiency as part of the refurbishment cycle. The Directive stipulates that whenever a building with a total useful floor area of over 1000m^2 undergoes major renovation, its energy performance must be upgraded to meet minimum requirements. This fits the profile of high-rise buildings and matches the argument for integration of energy efficiency into refurbishment: the chance must be taken to ensure the transposition of the Directive interprets it this way;
- the ESD addresses a wide range of barriers, including the removal of competing incentives in the interests of saving energy, the creation of a market for energy services and the requirement to introduce individual metering and billing for each end-user. Potential synergies with the EPBD exist, and the opportunities these present must be investigated further;
- widespread inadequate legislation or procedures governing the collective ownership of and decision-making about high-rise buildings or estates pose a significant barrier to implementing energy efficient refurbishments. Effective laws or codes of conduct are essential.

Socially,

- marketing and energy advice appropriate to the energy use culture and tailored to the individual to ensure energy efficient systems are used effectively is an essential part of any refurbishment, in particular to counter the barrier of entrenched energy use practices, such as opening windows and/or using secondary heating systems in response to the widespread problem in high-rise buildings of over- and/or under-heating;
- the potentially collective nature of living in high-rise buildings should be harnessed to get residents to support each others' energy-saving behaviour, especially in lieu of the requirements for individual metering and billing;
- employing tried and tested methods of holistic stakeholder involvement with both pre-refurbishment consultation and post-refurbishment evaluation of stakeholders' views, helps strengthen communities, eliminate potential problems before they arise and contributes to the body of good energy efficient refurbishment experiences, in turn helping to improve the often negative perception of high-rise living.

Policy Recommendations

In recognition of the cost-effective and very substantial CO_2 emissions reductions that can be achieved, especially in EU10 and AS3 countries but also in EU15 countries with the existing pattern of energy prices, we propose that policy makers:

- Recognise the inherent market failures and barriers to energy efficiency refurbishment that apply in the building sector as a whole, but most acutely in shared residences, and devise and implement policies to remedy them.
- Incorporate energy efficiency improvement as a legal requirement whenever refurbishment is undertaken in high-rise buildings to maximise cost-effectiveness of investment.
- Facilitate and support the creation of new European funds to accelerate sustainable, energy efficient refurbishment – especially for EU10 and AS3 countries where it is most needed, and because no structural funds for housing or energy demand management exist as yet.
- Consider adoption of Danish-style requirements for condominium dwellers to contribute a small monthly payment to a refurbishment fund.
- Consider introduction of fiscal incentives for refurbishment such as tax-deductions for refurbishments that improve the overall energy performance of the building or lower rates of tax on the rental income of landlords that improve the energy performance of their rental stock.
- In the case where high-rise residences are owned by local authorities, consider developing specific additional funds and obligations for energy-efficient refurbishment.
- Consider implementation of general energy efficiency delivery mechanisms that could be used, amongst other purposes, to fund energy-efficient refurbishment activities (potential examples include: a broadened version of the UK Energy Efficiency Commitment scheme and the Italian or French White certificate schemes).
- Prepare for energy market liberalisation, in particular in EU10 and AS3 countries, and ensure that individual metering and billing replaces the existing energy consumption infrastructure.
- Close gaps in building or estate level condominium legislation/collective decision-making rules to facilitate refurbishment.
- Link all actions to implementation of the Energy Performance of Buildings and Energy End-use Efficiency and Energy Services Directives.

Taking the opportunities identified in this study will require work to synchronise the objectives of various government departments and other authorities involved in the delivery of sustainable housing and energy. To this end there is a need to employ consistent methodologies across government to quantify the wider benefits of energy efficiency improvement and to commission further research to identify the most innovative forms of financing.

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ABBREVIATIONS

ACE	Association for the Conservation of Energy
BAT	best available technology
CEC	Commission of the European Communities
CEE	Central and Eastern Europe(an)
CIBSE	The Chartered Institution of Building Services Engineers
CHP	combined heat and power
CO_2	carbon dioxide
DHW	domestic hot water
DNO	distribution network operator
ECB	Energy Centre Bratislava
EPBD	Energy Performance of Buildings Directive
Eurima	European Insulation Manufacturers Association
EuroACE	European Alliance of Companies for Energy Efficiency in Buildings
ESCo	energy service company
ESD	Energy End-use Efficiency and Energy Services Directive
FRAMES	Framework Innovations for Building Renovation
HDD	heating degree day
IEA	International Energy Agency
kWh	kilowatt hour
LOCOSOC	Low Cost Social Housing (SAVE project)
RES	renewable energy sources
RUE	rational use of energy
SUREURO	Sustainable Refurbishment Europe
VROM	Netherlands Ministry of Housing, Spatial Planning and the Environment
WHO	World Health Organisation

1. INTRODUCTION

A wide range of projects have been and are being carried out in Europe which assess the costs, benefits and effectiveness of investment in residential energy efficiency refurbishment. In the context of pressing and frequently conflicting environmental, economic and social policy objectives, energy efficiency investment is repeatedly found to be a cost-effective and reconcilable component of energy policies. High-rise residential buildings are a particularly salient issue in this regard as their poor energy efficiency is regarded as a "moderate" to "major" problem by 19 out of 27 Housing Ministries who responded to a Europe-wide survey commissioned by the Ministries themselves. Yet no previous research exists on the Europe-wide picture of the potential for energy efficiency improvement in high-rise buildings.

The survey of Housing Ministries was commissioned by the 3rd Housing Ministers' Conference on Sustainable Housing in Genval, Belgium in June 2002, and carried out on behalf of VROM[2] by PRC Bouwcentrum International. It was agreed at the conference that the high-rise stock requires considerable improvement to meet sustainable quality norms, and that sustainable refurbishment and regeneration of surroundings should be undertaken as a priority to avoid social problems. A report has been produced entitled "*Sustainable Refurbishment of High-Rise Residential Buildings and Restructuring of Surrounding Areas*", informing the 4th Housing Ministers' Conference on Sustainable Housing in Prague, March 2005.

This research project's focus on energy efficiency fits firmly within the wider sustainable refurbishment[3] context. Jointly funded by the European Alliance of Companies for Energy Efficiency in Buildings (EuroACE) and the International Energy Agency, it investigates the scope for increased energy efficiency in high-rise buildings, carried out as part of their refurbishment, and discusses the benefits that investment in energy efficiency in these buildings can provide. The project considers the same geographical area: the present EU (25 Member States) plus Bulgaria, Romania and Turkey.

Data on the high-rise residential housing stock have been drawn from a variety of European sources, but originate mainly from the aforementioned survey, completed in 2004, of European Housing Ministries and from EuroACE members. At the Genval Conference, it was agreed to define high-rise residential buildings as having more than four storeys. Most of the high-rise stock was built from the 1950s to the 1980s and very often to poor energy efficiency and other construction standards. On average, one in six dwellings in the 28 European countries covered, are in high-rise buildings – 36 million dwellings in total. In some of the new Member States, up to 50% of the population live in high-rise buildings, most of which are in urgent need of general refurbishment, definable as the comprehensive renovation of the building and the repair of all its defects.

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[2] Netherlands Ministry of Spatial Planning, Housing and the Environment

[3] 'Sustainable refurbishment' is what is required to achieve 'sustainable *housing*', the definition of which was agreed at the Genval conference. See Annex I for details.

The project's first objective is to assess the current situation and argue for the integration of energy efficiency improvements into the refurbishment cycle of high-rise residential buildings: Sections 2 and 3 of this report. The second objective is to find a way forward by identifying barriers to and opportunities for doing this – reported on in Section 4 – and by illustrating the practical issues encountered through a series of good practice high-rise refurbishment case studies presented in Section 5. Section 6 synthesises the outcomes of the two objectives to reach overall conclusions and formulate recommendations.

2. POTENTIAL FOR ENERGY EFFICIENCY, INVESTMENT COST AND COST-EFFECTIVENESS

2.1. **Methodology**

Energy efficiency, or RUE[4], measures in the refurbishment of high-rise buildings considered for this project have been identified from the approach taken by the so-called *Trias Energica*[5]. This approach, applied to the buildings sector, prioritises actions taken to reduce energy demand and resulting CO_2 emissions. First, steps must be taken to reduce fabric energy losses. The second priority is to increase the use of renewable energy sources in meeting building energy demand, and the third and final priority is to otherwise ensure a more efficient use of fossil fuels. This project only considers RUE measures, hence focusing on priorities one and three:

- Improving the thermal properties of the building fabric – that is floors, roofs, walls and windows/doors, and
- improving the efficiency of heat generation and distribution in/for the building – more efficient boilers, implementation of balancing valves, pipe insulation, implementing or improving heating controls and so on.

The emphasis on the RUE measures listed above has been placed on reducing *heating* demand. Building fabric measures to reduce cooling demand where applicable (apart from the measures already listed, especially solar shading devices) have also been taken into account, but have not been incorporated into the formal model and are discussed separately in section 2.3.1. Furthermore, because this project makes the assumption that active-cooling systems are incompatible with the objective of reducing energy demand, the efficiency of cooling generation and distribution has not been considered. Sections 2.2 and 2.3 discuss the measures considered in more detail.

In order to model the potential for energy efficiency and the cost-effectiveness of investment in RUE measures, the 28 countries considered have been categorised according to both climate and socio-economic regions. Table 1 below illustrates how this has been carried out.

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[4] rational use of energy

[5] Lysen (1996)

Table 1:
Categorisation of Countries

	EU15	EU10	AS3
<2700 heating degree days (HDDs)	France, Greece, Italy, Portugal, Spain	Cyprus, Malta	Turkey
2700-3700 HDDs	Belgium, Ireland, Luxembourg, Netherlands, United Kingdom	Czech Republic, Hungary, Slovakia, Slovenia	Bulgaria, Romania
>3700 HDDs	Austria, Denmark[6], Finland, Germany, Sweden	Estonia, Latvia, Lithuania, Poland	-

EU15 countries are European Union countries that were members before 1st May 2004, EU10 countries are those that have joined the EU since, and AS3 countries are accession states[7]. The heating degree days (HDDs) are a reflection of a country's heating demand or climate. States in the <2700 group are warmer climate countries, countries in the 2700-3700 category experience more moderate climates, and those in the >3700 bracket have colder climates. The categorisation results in eight base regions, which have allowed the definition of eight reference high-rise buildings or base buildings, each broadly representative of the high-rise stock in its region. Figure 1 below maps out the base regions corresponding to the groupings in Table 1.

Each base region has initially been considered separately and it is assumed that each theoretical base building can be refurbished in every respect for the measures considered quantitatively. The base building representative of each base region has been considered in isolation. Following the logic of the *Trias Energica*, building fabric measures have been considered separately as well as in a package. Heating measures have been considered differently; heating controls have been considered both in isolation and in conjunction with the building fabric package; heating system replacements should only be assessed with the building fabric package and heating controls already in place[8].

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[6] Denmark is a borderline moderate/cold climate country. It has been typified as 'cold' because Denmark experiences a high wind-chill factor.

[7] In the case of Turkey: accession candidate.

[8] The reason for this is that boilers installed prior to a building fabric improvement would be oversized.

Figure 1:
Base Regions

The methodology applied in the Ecofys report for Eurima, "*Cost-Effective Climate Protection in the EU Building Stock*"[9], has been used to calculate the achievable reductions in energy demand in each base building in terms of:

- energy saved per m^2 of heated floor area,
- annualised/annual investment cost[10] per m^2 of heated floor area,
- simple payback time,
- (net) present cost per kWh of energy conserved,
- (net) present cost per tonne of CO_2 mitigated.

Crucially, because this project considers energy efficiency as one component of the sustainable refurbishment of high-rise buildings in line with the objectives of the 3rd European Housing Ministers' Conference on Sustainable Housing, the only costs of RUE measures considered are those that would not have occurred as part of an overall building refurbishment anyway. In the main, this implies that the cost of scaffolding has not been included in the cost of external wall insulation, for window replacement it means that only the additional cost for a high energy efficiency standard according to the best available technology (see 2.2) principle has been considered, with the same logic applied to boiler replacement.

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[9] Petersdorff *et al* (2004b); see Annex I.

[10] Annual investment cost works on the assumption that the necessary investment is financed over the course of the installed measures' economic lifetime (30 years for building fabric measures 20 years for heating measures). The discount/interest rate applied is 5%.

The reasoning for calculating cost-effectiveness on the basis of incorporating energy efficiency into a general, sustainable refurbishment approach is multi-faceted. Energy efficiency improvement is more cost-effective than if carried out separately (i.e. as a retrofit) because only the energy-related cost of the energy efficiency measures is counted. Furthermore, the survey of European housing ministries found that the two items "high-rise maintenance" and the "need for modernisation" of the high-rise stock are considered a "moderate" or "major" problem by 15 and 14 respondents respectively out of 27 housing ministries[11]. In light of compounding factors, including "moderate" or "major" problems pertaining to a disproportionately high incidence of low-income households (17 respondents) and unemployment (15 respondents) in the high-rise stock[11], there is an important and widespread need for accelerating the rates of high-rise refurbishment: The incorporation of energy efficiency generates immediate, tangible financial return on refurbishment, increasing financial acceptability. In short, there is unmet demand for refurbishment, and the incorporation of energy efficiency improvements can provides additional financial 'pull' on refurbishment rates and concomitantly reinforces the 'push' of European energy and CO_2-saving objectives. The summary of the cost-effectiveness assessment (section 2.5) includes an overall comparison of the energy-related cost-effectiveness with the cost-effectiveness of retrofit, i.e. assuming energy efficiency improvement is *not* carried out as part of general high-rise refurbishment.

Additionally, the energy demand reduction in high-rise buildings deemed achievable in the whole base building region has been included, based on the estimations provided by the European housing ministries in response to the VROM survey. These *stock-wide* assessments are quantitatively entirely separate from the results of modelling the refurbishment of *individual* base buildings. It is important to understand that the survey-based energy saving estimates are lower because a stock-wide assessment of energy saving potential does not assume that every high-rise building needs refurbishment to the same degree as individual base buildings.

Following a description of the measures considered in section 2.2 and a qualitative account of the energy efficiency measures not part of the model (section 2.3), section 2.4 assesses the potential for energy savings and CO_2 emissions reductions in each base region (both stock-wide and for individual base buildings), and quantifies the investment cost and associated cost-effectiveness of RUE measures included in the model for each base building. This is followed by a summary and conclusions in section 2.5.

2.2. **Measures considered in the Quantitative Model**

Throughout the quantitative assessment of the cost-effectiveness of energy efficiency measures, the rationale applied in terms of each measure's thermal properties has been the so-called best available technology or BAT principle. "Available" is defined as what is widely commercially available, and is

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[11] PRC Bouwcentrum International (2005)

thus not restricted to prototypes or demonstration projects. BAT is not necessarily the most cost-effective at the present time, but justification for employing the BAT principle arises from the fact that minimum European energy efficiency standards are set to continually rise under the requirements of the European Energy Performance of Buildings Directive and that energy prices in many of the regions considered are still below international market rates.

2.2.1. Building Fabric

According to the results of the VROM survey of European housing ministries, almost 50% of European high-rise stock was built between 1960 and 1980[12]. The construction techniques used for high-rise buildings in this era to a large degree determine what building fabric energy efficiency measures can be applied in the renovation cycle.

Wall Insulation

Three major wall construction techniques have been identified in the European high-rise stock. These are the use of *in situ* (cast on site) concrete, prefabricated concrete panels and load bearing brick[13]. The latter is more common in pre-1960 high-rise buildings because it preceded the widespread application of methods using concrete, and because the limitations that load bearing brick construction places on a tall building are more severe than concrete both technically and financially. Nevertheless, modern engineering has resulted in some load bearing brick high-rise construction up to 15-16 storeys high. In principle, cavity wall construction is possible with all three types, but has only been found to be a predominant type in the high-rise stock in conjunction with modern forms of bearing brick construction. Cavities do exist in concrete construction types with external (e.g. brick) cladding and render, but external wall insulation (applied when the cladding/render needs to be refurbished) rather than cavity wall insulation is considered in these cases due to the advantages in solving problems of thermal bridging in intermediate floors, balconies and access walkways.

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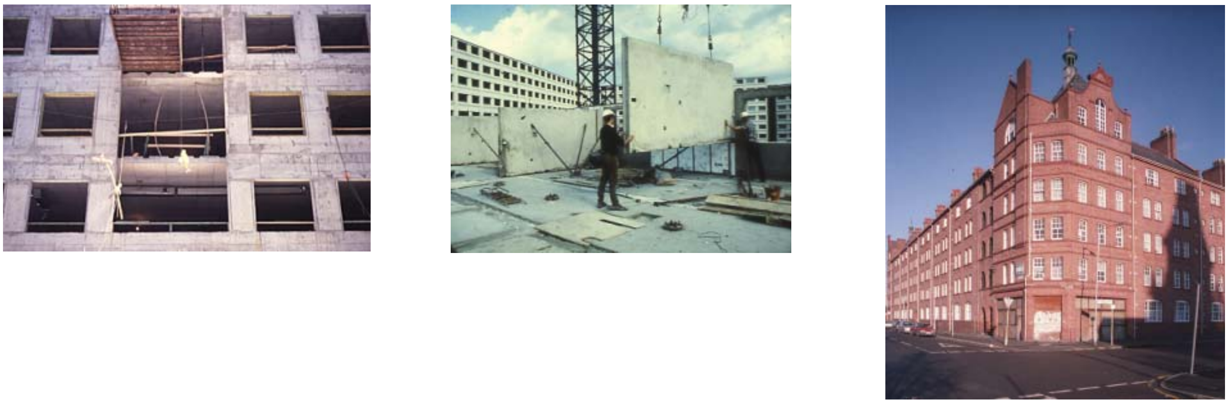
[12] Approximately 20% of European high-rise stock was built before 1960, and 30% has been built after 1980.

[13] Brick is often used for the construction of external walls between the columns of an *in situ* concrete frame, but this type of brick usage is not "load bearing", and thus defined as *in situ* concrete construction.

Figure 2:
Main Wall Construction Types[14]



a) in situ concrete b) prefab concrete panels c) load bearing brick

Roof Insulation

High-rise buildings can have either pitched or flat roofs, although the overwhelming majority of post-1960 buildings are likely to have been constructed with flat roofs. The immediate option, simultaneously the option considered quantitatively, is the application of warm deck insulation. However other, less direct possibilities for insulating high-rise roofs exist, including constructing a pitched roof with loft insulation (much higher investment, lower maintenance), or even constructing an additional storey with new apartments and a pitched roof. The latter can obviously generate additional returns through sale or lease of new dwellings[15].

Figure 3:
Warm Deck Flat Roof Insulation[16]

a) application b) with waterproof layer

Figure 4:
New Roof/storey[17]

Floor Insulation

With respect to floors, there are two main possibilities for insulation considering that the majority of high-rise buildings' lowest floors are of a solid concrete construction. If there is no basement or the ground

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[14] Photo a) from School of Architecture, McGill University (1998); b) from The Concrete Society (2004); c) from Manchester Online (1999).

[15] See section 5.6.

[16] Photos a) and b) are from the Estonian Energy Research Institute (2004).

[17] Photo from Sonne (2003)

floor is above a heated basement, the main option is to improve the thermal qualities of the floor by using an insulation/chipboard composite; however this may entail additional costs related to shortening doors and installing raised thresholds. If the ground floor is above an unheated basement, the best approach is to insulate the basement ceiling.

Window Replacement

Replacement windows can theoretically take any combination of double or triple, low emissivity and/or gas-filled glazing, in metal, plastic or wood frames – along with their various associated U values and g values.

The U value (or “thermal transmittance”) is the better known property as it is a term which also applies to the opaque parts of the building envelope. Window U values are lowered (ie improved) mainly through the use of low emissivity (low E) glass; low E refers to a microscopically thin coating on the glass which does not significantly inhibit the transmission of short-wave energy from the sun into a building, but is highly reflective to the long-wave energy produced by the building’s internal heat sources. Thus much less heat is lost through low E glazing than through conventional uncoated glass. The U value of a double or triple glazed unit containing low E glass can be further enhanced if the cavities are filled with an inert gas – usually either argon or krypton – or the traditional aluminium spacer bar separating the glass panes is replaced by an advanced insulating spacer. The windows considered as replacements in this study are all low E and gas filled.

The g value (or “solar transmittance”) is a less well-known term, as it applies only to a transparent material. It is quite simply a number expressing the fraction of solar energy which is transmitted; a g value of 0.7 means that 70% of the incident solar energy is transmitted and 30% rejected. The g value of a glass is modified by the particular type of low E coating, and a wide range is manufactured. In moderate and cold climates, a high g value is beneficial as it means a large proportion of solar heat is admitted, thereby offsetting part of the demand of conventional heating. In hot climates, or in air-conditioned buildings, low g values are likely to be more beneficial.

The replacement window types considered in the cost-effectiveness assessment have been selected with the assistance of EuroACE members to suit the regional climatic conditions and materials used, and act as suitable upgrades given the predominant existing window types. As an example, triple-glazed windows have been modelled as replacements in cold climate regions, but not at all in warm climate regions. Generally, single or secondary-glazed windows have not been considered as replacements.

Heating System

These measures, as for building fabric measures, have only been considered at the building level. Electric heating systems – storage heating or non-fixed appliances – are assumed to have 100% system efficiency for the calculation of useful energy demand, building and dwelling-based central heating systems are assumed to have a system efficiency of 75% and district heating networks an efficiency of 80% in terms of useful energy demand.

Distribution

The heat distribution measures considered quantitatively are thermostatic radiator valves (TRVs) and balancing valves. To illustrate the importance of this, dwellings closest to a centralised source of heat[18] tend to suffer overheating whilst dwellings furthest away (highest up) from the heat source tend to be under-heated. Residents of upper floor flats may use additional heating appliances to meet their demand and occupants of lower floor dwellings may open windows to cool down, resulting in both increased energy consumption and wasted energy. Balancing valves are installed on the so-called 'risers', the vertically oriented heat pipes in the building, to ensure an even distribution of heat throughout the building. TRVs further enable the control of temperature on a radiator-by-radiator (room-by-room) basis, with substantial potential to save energy by reducing heating where it is not required. Savings for these measures are assumed to be 30%[19] of the heating demand prior to their installation. There are two important points regarding TRVs and balancing valves. First, they save a larger amount of heating energy when installed in an un-insulated building compared to an otherwise refurbished building – 30% of heating demand in each case. Second, the contribution of TRVs to reducing heating demand is dependent on their proper use, so guidance for tenants is as important as the installation itself. Balancing valves and TRVs have not been applied to base buildings A and B as these are assumed to be heated by dwelling-based electric heating systems or appliances.

Both measures also increase comfort levels by ensuring consistent and controllable temperatures. Improved comfort and wellbeing benefits, which are not part of the quantitative assessment, are discussed in section 3.4.

Generation

Energy efficiency improvements in terms of heating generation have been considered quantitatively in the base buildings where on-site boiler replacements are possible. The best available condensing boiler technology has been considered. Off-site improvements, such as in the case of district heating generation, and replacements of the heating system infrastructure (e.g. replacing electric with gas central heating)

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[18] I.e. ground floor dwellings in a high-rise building supplied by district heat or a boiler supplying the whole building.

[19] With a 20% contribution from TRVs and 10% from balancing valves.

have not been considered. In order to maintain comparability with base buildings where boiler replacements are not possible, additional savings due to improvements in domestic hot water generation efficiency have only been reported in individual base buildings' subsections[20] and not in the summary section (2.5).

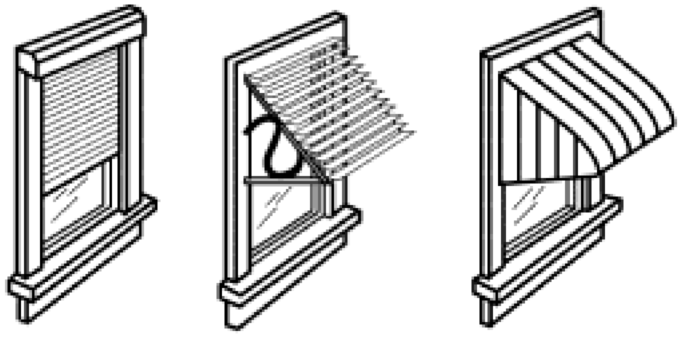
2.3. **Other Measures' Contributions**

2.3.1. Building Fabric

External Solar Shading

External solar shading is particularly beneficial for reducing cooling demand and increasing thermal comfort. There are two key elements to maximising the energy saving potential of solar shading devices. First, the lower the so-called g-value, the better: a value of 0.1 means that the shading device arrests 90% of the solar energy directed at it. Second is the implementation of an automatic control system that can act to minimise excessive solar gain in the summer regardless of whether residents are present in the dwelling. External solar shading devices have a variety of forms and materials; Figure 5 below illustrates a few of the major forms.

Figure 5:
Examples of External Solar Shading Device[21]



a) roller blind b) Venetian awning c) hood awning

Other forms include fixed louvers and laterally sliding panels, and taken together with the wide variety of materials (fibreglass, wood, textiles, metal), this means that there is the possibility to configure external shading measures to suit almost any type of high-rise building.

Depending on the amount and orientation of glazing on a building, external solar shading measures are capable of reducing interior temperatures by 6 to 8 °C on a hot day, reducing cooling demand by 30 to

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[20] This is necessitated by the fact that boiler replacements' direct contribution to reduced DHW energy expenditure increases their cost-effectiveness.

[21] Figures a), b) and c) are from the California Energy Commission (2004).

50% in warm climates and avoiding the need for air-conditioning altogether in some more moderate climates.

The indicative investment cost per m^2 for a commonly available fibreglass fabric roller-blind is about €80 to €100. The level of automation, size, and choice of fabrics may raise or lower the investment cost by about 10 to 20%. Depending on climate, g-values, glazing characteristics and energy prices, external solar shading devices can have a payback period of four to six years.

Effect of insulation and windows on cooling demand

Petersdorff *et al* (2004a) have modelled the effect of insulation including windows on cooling demand in moderate and warm climate countries. A number of important conclusions were drawn:

- Windows' g-values have a more significant effect on reducing cooling demand than their U values.
- Ground floor insulation increases cooling demand, but it is generally only in warm climate countries that this increase outweighs the reduction in heating demand.
- It is possible for insulation to increase cooling demand as a result of heat gains being retained in the building more effectively.
- The additional effect of insulation on reducing cooling demand in a given climate is greatest where the heat load has been minimised (e.g. through external solar shading, efficient appliances and effective ventilation).
- With the exception of the roof or top storey, the additional effect of insulation on reducing cooling demand is negligible in moderate climate countries.

2.3.2. Heating/Cooling System

Distribution

Insulation of central heating and domestic hot water distribution pipes is fairly inexpensive. Applying this measure to un-insulated and above all accessible pipes is likely to be highly cost-effective as it improves system efficiency at relatively low cost. However, very little is known about the state of pipe insulation in high-rise buildings across Europe and indeed research to quantify the energy and CO_2 benefits has only recently been undertaken[22], which is why this measure has not been considered quantitatively.

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[22] See Zentrum für Umweltbewusstes Bauen e. V. (2004)

Figure 6:
Foam Pipe Insulation[23]

In addition to the installation of balancing valves and TRVs outlined in section 0, parallel rather than sequential alignment of radiators can also help ensure even heat distribution within a high-rise building and contribute to improved comfort levels.

Generation

Alternative forms of heat generation can be considered. Combined heat and power systems qualify as a RUE measure and fulfil the objective of saving energy. Renewable heat generation at the building level, wood chip and wood pellet boilers in particular, would contribute to an objective of reducing CO_2 emissions.

Cooling

While European ownership of air-conditioning units is still very low – about 0.02 per household[24] – compared to the US, Japan and Australia, the market for cooling technologies is growing very quickly. Data on cooling energy consumption is very poor, but the emphasis in high-rise refurbishment with respect to cooling should be placed firmly on averting or reducing the need for active cooling systems. This is equivalent to priority one measures under the *Trias Energica*, and would include passive solar design, better thermal performance (see 2.3.1), appropriate ventilation strategies, heat recovery and utilisation, reducing internal heat loads, day-lighting and increasing building albedo. Priority two measures include using renewable energy-based active cooling technologies – for example solar cooling or ground-source heat cooling. Priority three – where active cooling technologies are present – would involve efficient heat pump designs installations.

2.3.3. Lighting

During refurbishment, electric lighting in common areas of high-rise buildings can be easily upgraded. In general, all incandescent lighting should be examined, using a variety of more efficient lighting technologies as replacements. Indoor incandescent bulbs in corridors, lobbies, stairwells, laundry rooms

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[23] Practical Help (2004)

[24] IEA (2004)

and other common areas can be replaced with linear or compact fluorescent lamps. Timers, occupancy sensors and daylight dimming can be used to avoid unneeded illumination. Luminaires with superior performance can be used and steps taken to avoid over-illumination by following best practice regarding indoor illuminance levels. Outdoors, high pressure sodium and efficient metal halide fixtures can take the place of incandescent lights or mercury vapour lamps and may be combined with timers or photocells to ensure they are off during daylight hours. Furthermore, replacing incandescent lamps and some types of fluorescent lighting in emergency lighting and exit signs with efficient light emitting diodes (LEDs) will also save energy. Natural lighting design can help minimise electric lighting requirements. Virtually every aspect of window design as described in section 2.2.1 has a bearing on sunlight entering the building. Natural lighting strategies should be given due consideration and integrated appropriately with the choice of window replacement, electric lighting.

2.3.4. Ventilation

Improvement of the building fabric and thermal properties of any building will lead to increased air-tightness. If unmitigated, this results in a lower rate of renewal of indoor air, and will lead to an increased incidence of condensation and mould growth, hazardous to the health and wellbeing of residents. Some types of high-rise construction, in particular prefabricated concrete panel constructions with solid concrete floors, can already be inherently very airtight, unless windows are poorly fitted[25]. In any case any refurbishment must incorporate the installation of appropriate ventilation systems. This of course reduces the energy-saving potential of other measures, but is imperative to safeguard the health and wellbeing of occupants. In the interests of maximising energy savings, heat recovery ventilation – which can potentially reduce ventilation loss by up to 75% – should be installed in colder regions to minimise the ventilation loss.

Natural ventilation systems can provide an important and zero energy means of providing fresh air whilst also reducing cooling demand. Dwelling-based ventilation outlets combined with the use of windows help to achieve the required ventilation. Natural ventilation is particularly suitable for high-rise buildings because ventilation stacks with intakes at low or ground level and exhaust vents at the top of the building increase in effectiveness the taller they are. However, given that careful whole-building design is needed to achieve ventilation of the right parts of the building at the desired rate, a limitation of natural ventilation systems is that they can prove difficult to incorporate into the refurbishment of existing high-rise buildings. Nevertheless, natural ventilation in high-rise residential buildings combined with efforts to minimise solar and internal gain, has the potential to be "as effective as a space cooling system"[26]. Its feasibility should thus be carefully assessed, particularly in warm and mixed-climate countries.

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[25] See http://www.est.co.uk/bestpractice/hardtotreat/1960highrise.cfm.

[26] Advanced Buildings (2004)

2.4. Results for Base Regions and Buildings[27]

2.4.1. Warm Climate EU15 Countries: Region A

Headline Facts and Figures, Stock-wide:

- Broadly representative of France, Greece, Italy, Portugal and Spain.
- 19.5 million dwellings.
- 650,000 buildings (theoretical).
- 24% of dwellings in the region.
- Energy-saving potential in stock: 25%, equivalent to 1.3% of region's final energy demand or 10 $MtCO_2$ emissions.

Predominant Construction and Heating Features:

- *In situ* concrete walls, flat concrete roof and concrete floor, single-glazed, metal frame windows.
- Dwelling based electric systems or appliances.

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[27] For details of the methodology used throughout this section and key assumptions made for the modelling of energy demand reduction, please see Annex II.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 2:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building A

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	2.37	0.46	66.6	35.7%	1.32	2.0	2.8
Roof	3.00	0.39	22.5	12.1%	0.17	0.8	1.1
Floor	2.93	0.47	21.3	11.4%	0.18	0.9	1.2
Windows	4.56	2.64	22.2	11.9%	0.93	4.2	5.8
Package	2.93	0.85	132.6	71.0%	2.61	2.0	2.7

Table 3:
Energy Savings, Costs of Energy and of CO_2 Mitigation, Base Building A

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	66.6	35.7%	12.4	2.0	-10.4	95	-496
Roof	22.5	12.1%		0.8	-11.6	36	-554
Floor	21.3	11.4%		0.9	-11.6	40	-550
Windows	22.2	11.9%		4.2	-8.2	199	-391
Package	132.6	71.0%	12.4	2.0	-10.4	93	-497

Issues

- Second lowest heating demand region.
- France is a borderline case between a warm and a moderate climate country. As a result the characteristics of its high-rise building stock can be expected to vary widely, but it has been categorised as warm climate because it is believed the majority of its high-rise stock is in the southern regions.
- The cost-effectiveness of RUE investment in this region appears to be amongst the best. This is due to the low initial thermal quality of the buildings to be refurbished, the relatively low investment cost and higher-priced energy carriers. But the difference between theoretical heating demand based on heating degree days and actual energy used for heating is likely to be large because temperatures don’t drop as far, or as quickly as in colder climes.

2.4.2. Warm Climate EU10 Countries: Region B

Headline Facts and Figures, Stock-wide

- Broadly representative of Cyprus and Malta.
- 132,000 dwellings.
- 4,500 buildings (theoretical).
- 28% of dwellings in the region.
- Energy-saving potential in stock: 25%, equivalent to 1% of region's final energy demand or 0.06 $MtCO_2$ emissions.

Predominant Construction and Heating Features

- *In situ* concrete walls, flat concrete roof and concrete floor, single-glazed, metal frame windows.
- Dwelling based electric systems or appliances.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 4:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building B

	U-value before ($W/m^2°C$)	U-value after ($W/m^2°C$)	Energy saved [kWh/m^2a]		Annual investment cost [€/m^2a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	2.60	0.48	64.1	37.3%	0.97	1.5	5.5
Roof	3.40	0.43	22.2	12.9%	0.15	0.7	2.5
Floor	3.40	0.48	21.8	12.7%	0.17	0.8	2.9
Windows	4.20	2.71	15.0	8.7%	0.78	5.2	18.9
Package	3.11	0.88	123.1	71.7%	2.08	1.7	6.1

Table 5:
Energy Savings, Costs of Energy and of CO_2 Mitigation, Base Building B

	Energy saved [kWh/m^2a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	64.1	37.3%	4.8	1.5	-3.2	75	-160
Roof	22.2	12.9%		0.7	-4.1	34	-201
Floor	21.8	12.7%		0.8	-4.0	39	-196
Windows	15.0	8.7%		5.2	0.4	257	21
Package	123.1	71.7%	4.8	1.7	-3.1	84	-152

Issues

- Heating demand is the lowest of the regions.
- Malta poses issues not present in any other European country considered, because the government subsidises household energy very heavily – it costs about 0.29c/kWh$_e$. As a consequence, building a financial argument for private citizens in the same way as for the other base buildings for investment in energy efficiency is not possible. This is not the case if the economic arguments are assessed from a societal perspective.

2.4.3. Warm Climate AS3 Countries: Region C

Headline Facts and Figures, Stock-wide

- Broadly representative of Turkey.
- 3.5 million dwellings.
- 73,000 buildings (theoretical).
- 22% of dwellings in the region.
- Energy-saving potential in stock: 25%, equivalent to 1.7% of region's final energy demand or 2.4 $MtCO_2$ emissions.

Predominant Construction and Heating Features

- *In situ* concrete walls, flat concrete roof and concrete floor, single-glazed, metal frame windows.
- Dwelling-based gas central heating (combi-boilers), allowing installation of TRVs and replacement with condensing combi-boilers.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 6:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building C

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	1.20	0.30	51.9	31.9%	0.78	1.5	14.0
Roof	2.17	0.24	20.7	12.7%	0.10	0.5	4.6
Floor	1.20	0.41	8.5	5.2%	0.12	1.4	12.8
Windows	3.00	1.80	23.1	14.2%	0.65	2.8	26.3
Package	1.66	0.60	104.1	63.9%	1.65	1.6	14.7
TRVs			32.6	20%	0.21	0.6	4.6
All of the above combined			115.9	71.1%	1.85	1.6	14.5
+ boiler replacement			126.6	77.7%	2.62	1.9	16.2
DHW effect			*12.2*	*22.7%*			

Table 7:
Energy Savings, Costs of Energy and of CO$_2$ Mitigation, Base Building C

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO$_2$ mitigation [€/tCO$_2$]	Net cost of CO$_2$ mitigation [€/tCO$_2$]
Walls	51.9	31.9%	1.9	1.5	-0.4	74	-17
Roof	20.7	12.7%		0.5	-1.4	24	-68
Floor	8.5	5.2%		1.4	-0.5	68	-24
Windows	23.1	14.2%		2.8	1.0	139	48
Package	104.1	63.9%	1.9	1.6	-0.3	78	-14
TRVs	32.6	20%		0.6	-1.2	31	-61
All above	115.9	71.1%		1.6	-0.3	79	-13
+ boiler	126.6	77.7%	1.9	1.9	0.0	93	2
DHW effect	*12.2*	*22.7%*					

Issues

- Nearly all data provided by the Turkish housing ministry is about the housing stock as a whole.
- In terms of climate, Turkey has parallels with France; it is a borderline case between a warm and a moderate climate – it even has few very cold regions – and is likely to have large simultaneous geographical and seasonal climate variability. This is likely to be reflected in a very wide variety of high-rise construction types.

2.4.3. Moderate climate EU15 countries: region D

Headline Facts and Figures, Stock-wide

- Broadly representative of Belgium, Ireland, Luxembourg, the Netherlands and the United Kingdom.
- 1.2 million dwellings.
- 38,000 buildings (theoretical).
- 6.4% of dwellings in the region.
- Energy-saving potential in stock: 30%, equivalent to 0.5% of region’s final energy demand or 5.3 $MtCO_2$ emissions.

Predominant Construction and Heating Features

- Prefabricated concrete panel walls, flat concrete roof and concrete floor over unheated basement, double-glazed, wood frame windows.
- Building-based gas central heating, allowing installation of TRVs and balancing valves and replacement of existing boiler with condensing boiler.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 8:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building D

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	1.61	0.46	77.7	32.7%	1.70	2.2	4.3
Roof	1.46	0.27	17.2	7.3%	0.26	1.5	3.0
Floor	1.79	0.51	18.4	7.8%	0.18	1.0	2.0
Windows	3.38	1.77	39.2	16.5%	1.56	4.0	7.8
Package	1.97	0.71	152.6	64.2%	3.70	2.4	4.8
TRVs			71.3	30.0%	0.24	0.3	0.8
All of the above combined			178.1	74.9%	3.94	2.2	4.5
+ boiler replacement			191.2	80.5%	3.99	1.9	4.0
DHW effect			*17.3*	*22.1%*			

Table 9:
Energy Savings, Costs of Energy and of CO_2 Mitigation, Base Building D

	Energy saved [kWh/m^2a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	77.7	32.7%	8.8	2.2	-6.6	95	-287
Roof	17.2	7.3%		1.5	-7.3	65	-317
Floor	18.4	7.8%		1.0	-7.8	43	-340
Windows	39.2	16.5%		4.0	-4.8	174	-209
Package	152.6	64.2%	8.8	2.4	-6.3	106	-277
TRVs	71.3	30.0%		0.3	-5.5	15	-240
All above	178.1	74.9%		2.2	-6.1	97	-268
+ boiler	191.2	80.5%	8.8	1.9	-6.2	84	-271
DHW effect	*17.3*	*22.1%*					

Issues

- Lowest dwellings proportion. High heterogeneity (between and within countries), both in terms of construction type and heating system type. Ireland has mainly dwelling-based electric heating.
- The cost-effectiveness of measures for Ireland, because of the use of electricity as the main heating energy carrier, is higher than the figures in the data table for the region as a whole suggest.

2.4.4. Moderate Climate EU10 Countries: Region E

Headline Facts and Figures, Stock-wide

- Broadly representative of the Czech Republic, Hungary, Slovakia and Slovenia.
- 3 million dwellings.
- 50,000 buildings (theoretical).
- 27% of dwellings in the region.
- Energy-saving potential in stock: 39%, equivalent to 2.5% of region’s final energy demand or 4 $MtCO_2$ emissions.

Predominant Construction and Heating Features

- Prefabricated concrete panel walls, flat concrete roof and concrete floor, double-glazed, wood frame windows.
- District heating, allowing installation of TRVs and balancing valves.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 10:
Energy savings, investment costs and cost of conserved energy, base building E

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	1.20	0.30	60.1	33.1%	0.92	1.5	8.7
Roof	2.17	0.24	21.7	12.0%	0.15	0.7	3.8
Floor	1.10	0.45	7.3	4.0%	0.13	1.7	9.9
Windows	2.90	1.70	26.7	14.7%	0.71	2.7	15.2
Package	1.63	0.59	115.8	63.8%	1.91	1.6	9.3
TRVs			54.5	30.0%	0.19	0.3	1.6
All of the above combined			135.5	74.7%	2.10	1.5	8.6

Table 11:
Energy Savings, Costs of Energy and of CO_2 Mitigation, Base Building E

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	60.1	33.1%	3.0	1.5	-1.5	67	-66
Roof	21.7	12.0%		0.7	-2.4	29	-104
Floor	7.3	4.0%		1.7	-1.3	76	-57
Windows	26.7	14.7%		2.7	-0.4	117	-16
Package	115.8	63.8%	3.0	1.6	-1.4	72	-61
TRVs	54.5	30.0%		0.3	-2.7	15	-118
All above	135.5	74.7%		1.5	-1.5	68	-66

Issues

- Energy saving potential is the highest amongst the regions.

2.4.5. Moderate Climate AS3 Countries: Region F

Headline Facts and Figures, Stock-wide

- Broadly representative of Bulgaria and Romania.
- 1.9 million dwellings.
- 40,000 buildings (theoretical).
- 22% of dwellings in the region.
- Energy-saving potential in stock: 31%, equivalent to 2.2% of region's final energy demand or 1.1MtCO_2 emissions.

Predominant Construction and Heating Features

- Prefabricated concrete panel walls, flat concrete roof and concrete floor, double-glazed, wood frame windows.
- District heating, allowing installation of TRVs and balancing valves.

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 12:
Energy savings, investment costs and cost of conserved energy, base building F

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	1.20	0.30	61.4	33.7%	0.78	1.3	11.0
Roof	2.17	0.24	24.4	13.4%	0.11	0.4	3.8
Floor	1.10	0.45	8.2	4.5%	0.13	1.6	13.7
Windows	2.60	1.30	29.6	16.2%	0.64	2.2	18.8
Package	1.57	0.51	123.7	67.8%	1.66	1.3	11.6
TRVs			54.7	30.0%	0.11	0.2	1.3
All of the above combined			141.3	77.4%	1.77	1.3	10.7

Table 13:
Energy savings, costs of energy and of CO_2 mitigation, base building F

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	61.4	33.7%	2.0	1.3	-0.7	55	-32
Roof	24.4	13.4%		0.4	-1.6	19	-68
Floor	8.2	4.5%		1.6	-0.4	69	-18
Windows	29.6	16.2%		2.2	0.2	95	8
Package	123.7	67.8%	2.0	1.3	-0.7	59	-29
TRVs	54.7	30.0%		0.2	-1.8	8	-79
All above	141.3	77.4%		1.3	-0.7	55	-33

Issues

- Very low fuel prices make investment one of the least cost-effective of all regions. However, this would change if market rates begin to apply in the future.

2.4.6. Cold Climate EU15 Countries: Region G

Headline Facts and Figures, Stock-wide

- Broadly representative of Austria, Denmark, Finland, Germany and Sweden.
- 5.2 million dwellings.
- 141,000 buildings (theoretical).
- 20% of dwellings in the region.
- Energy-saving potential in stock: 28%, equivalent to 1.5% of region's final energy demand or 6.7 MtCO$_2$ emissions.

Predominant Construction and Heating Features

- Prefabricated concrete panel walls, flat concrete roof and ground floor above an unheated basement, double-glazed, wood frame windows.
- District heating, allowing installation of TRVs and balancing valves.

Cost effectiveness of Energy Efficiency Investment, Individual Base Building

Table 14:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building G

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	0.91	0.27	62.7	27.7%	1.33	2.1	5.1
Roof	1.66	0.22	31.0	13.7%	0.31	1.0	2.4
Floor	0.89	0.29	12.9	5.7%	0.31	2.4	5.8
Windows	2.87	1.41	41.6	18.4%	1.87	4.5	10.9
Package	1.33	0.46	148.3	65.5%	3.82	2.6	6.2
TRVs			67.9	30.0%	0.25	0.4	0.7
All of the above combined			171.6	75.9%	4.07	2.4	5.7

Table 15:
Energy Savings, Costs of Energy and of CO_2 Mitigation, Base Building G

	Energy saved [kWh/m^2a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
Walls	62.7	27.7%	7.1	2.1	-5.0	86	-205
Roof	31.0	13.7%		1.0	-6.1	41	-250
Floor	12.9	5.7%		2.4	-4.7	98	-193
Windows	41.6	18.4%		4.5	-2.7	183	-109
Package	148.3	65.5%	7.1	2.6	-4.6	105	-186
TRVs	67.9	30.0%		0.4	-6.8	15	-276
All above	171.6	75.9%		2.4	-4.8	97	-195

Issues

- Considering the number of heating degree days, Denmark is a borderline moderate/cold climate country. However, the wind-chill factor is quite high, making it more of a cold climate country.
- Slightly below average dwellings proportion, more variable construction types (as with base building D). District heating is predominantly used in Denmark, Finland and Sweden, but also widely used in Austria and Germany.
- Cost-effectiveness of investment in high-rise stock in this region is in the middle range.

2.4.7. Cold Climate EU10 Countries: Region H

Headline Facts and Figures, Stock-wide

- Broadly representative of Estonia, Latvia, Lithuania and Poland.
- 6.1 million dwellings.
- 125,000 buildings (theoretical).
- 41% of dwellings in the region.
- Energy-saving potential in stock: 34%, equivalent to 4.4% of region's final energy demand or 9.3 $MtCO_2$ emissions.

Predominant Construction and Heating Features

- Prefabricated concrete panel walls, flat concrete roof and ground floor above an unheated basement, secondary-glazed, plastic frame windows
- District heating, allowing installation of TRVs and balancing valves

Cost Effectiveness of Energy Efficiency Investment, Individual Base Building

Table 16:
Energy Savings, Investment Costs and Cost of Conserved Energy, Base Building H

	U-value before (W/m^2°C)	U-value after (W/m^2°C)	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback time [years]
Walls	1.00	0.28	62.2	30.9%	0.96	1.5	11.8
Roof	0.90	0.30	9.9	4.9%	0.04	0.4	2.9
Floor	0.90	0.45	7.4	3.7%	0.14	1.9	14.9
Windows	3.00	1.80	34.3	17.0%	0.65	1.9	14.5
Package	1.37	0.59	113.9	56.6%	1.79	1.6	12.1
TRVs			60.4	30.0%	0.15	0.3	1.5
All of the above combined			140.2	69.6%	1.95	1.4	10.5

Table 17:
Energy Savings, Costs of Energy and of CO$_2$ Mitigation, Base Building H

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO$_2$ mitigation [€/tCO$_2$]	Net cost of CO$_2$ mitigation [€/tCO$_2$]
Walls	62.2	30.9%	2.3	1.5	-0.7	63	-29
Roof	9.9	4.9%		0.4	-1.9	15	-77
Floor	7.4	3.7%		1.9	-0.3	79	-13
Windows	34.3	17.0%		1.9	-0.4	77	-15
Package	113.9	56.6%	2.3	1.6	-0.7	64	-28
TRVs	60.4	30.0%		0.3	-2.0	10	-82
All above	140.2	69.6%		1.4	-0.9	57	-36

Issues

- Highest dwelling proportion, second highest energy saving potential and CO$_2$ reductions.
- Fairly homogeneous high-rise stock.
- Low cost-effectiveness of investment due to low energy prices.

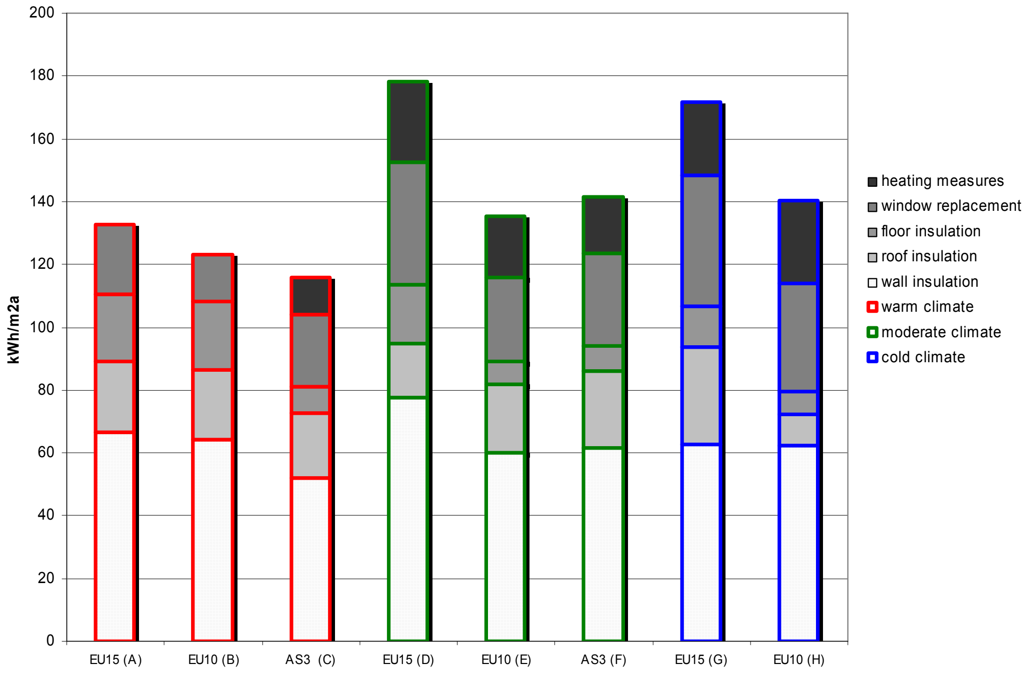
2.5. SUMMARY AND CONCLUSIONS

2.5.1. Individual Base Buildings

Energy Savings

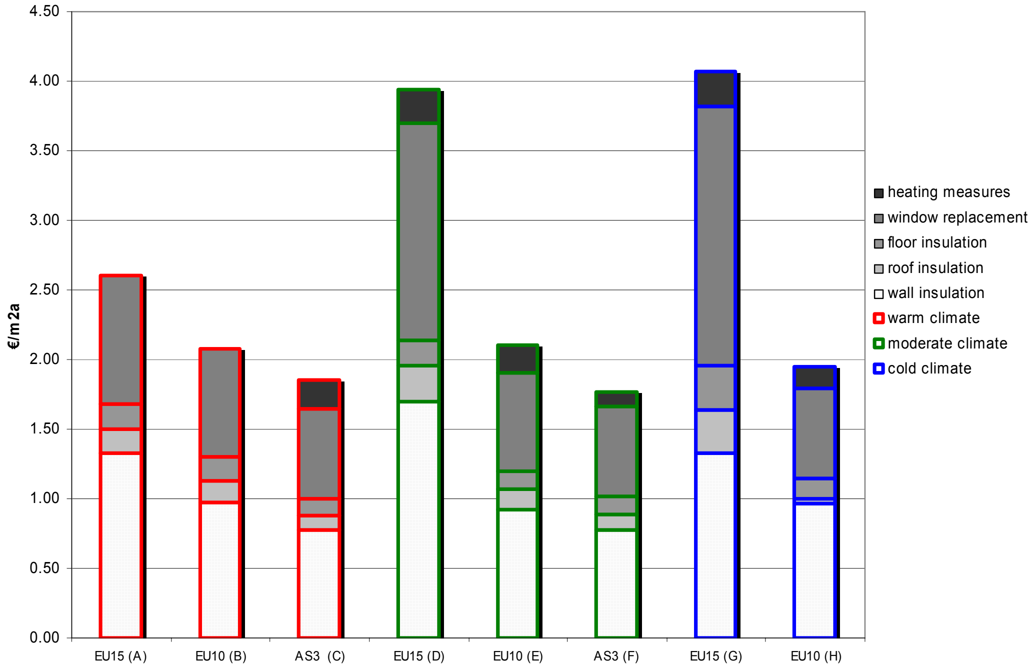
Figure 7 outlines the heating demand reductions achievable in each base building. It can be seen that the savings vary considerably between warmer (buildings A to C) and colder countries.

Figure 7:
Heating Demand Reduction – All Measures



The reductions in heating demand achievable are between 70 and 80 per cent. Naturally, the costs of including these measures in refurbishment vary considerably as a result of different labour and capital costs in the base regions, as Figure 8 illustrates.

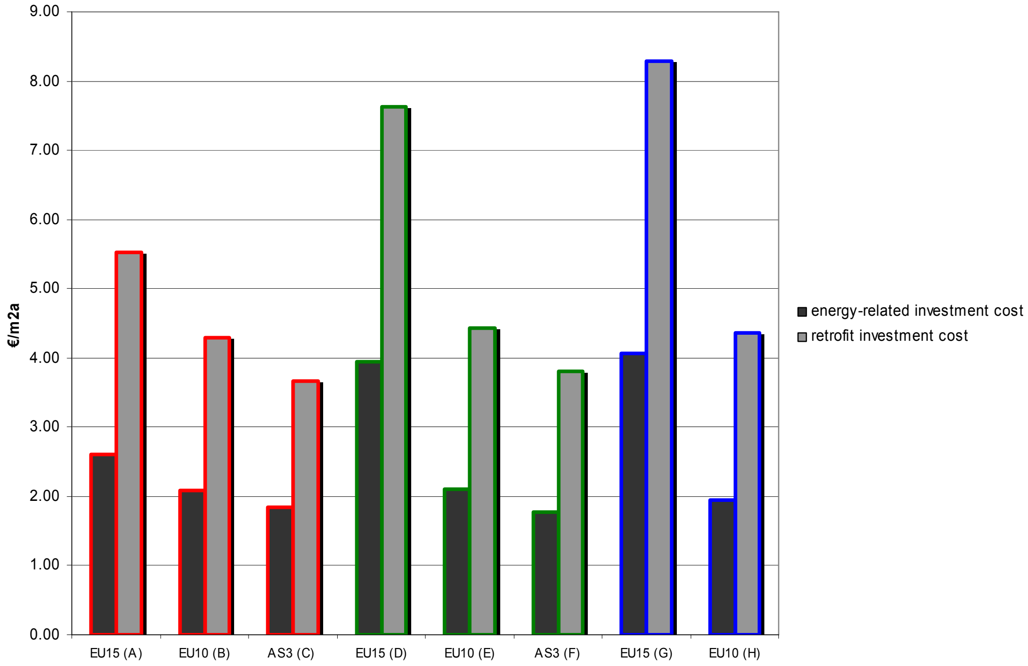
Figure 8:
Annualised Investment Cost



The capital costs are also partially determined by the standard of the energy saving measures included in the refurbishment – usually the better the thermal properties, the more costly. Unsurprisingly window replacement and wall insulation (where external) are the highest-cost measures per m^2 of heated floor area; for the former this is due to the sophistication of the product compared, and for the latter it is due to the large wall surface area. Base buildings D and G are the most costly to refurbish overall, but are also in the regions with the highest per capita income.

Figure 9 compares the energy-related investment cost illustrated in Figure 8 with what it would cost to improve energy efficiency separately from general refurbishment; it can be seen that the cost approximately doubles.

Figure 9:
Energy-related and Retrofit Investment Cost

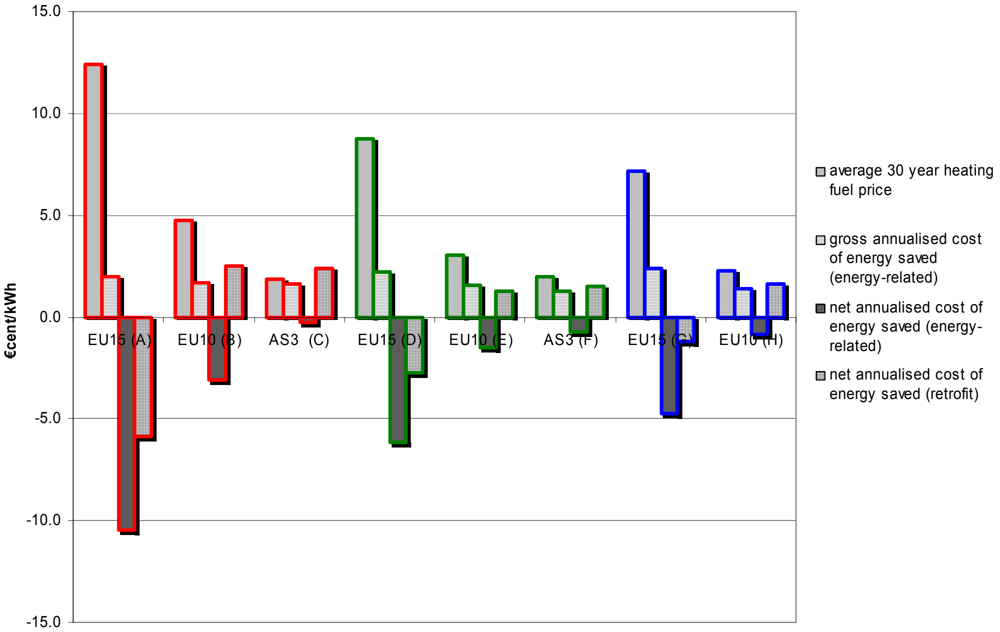


The cost-effectiveness of the package of measures in terms of energy savings can be calculated in two ways. The first divides the annualised investment cost per m^2 (Figure 8) by the energy savings per m^2 per year (Figure 7); this is illustrated by the "gross annualised cost of energy saved" bars in Figure 10. The second calculation of cost-effectiveness additionally takes energy prices and reduced household energy expenditure into account, giving the "net annualised cost of energy saved" (also in Figure 10).

As explained in section 2.1, annualised investment cost implies that the energy efficiency measures are financed over the course of their economic lifetimes, as would be the case if householders take out a loan to finance the investment. Not taking energy prices and expenditure into account, the most cost-effective investment can be made in base buildings C, E, F and H. These are the EU10 (excluding Cyprus and Malta) and AS3 countries. Initially fairly low energy efficiency standards combined with low capital and labour costs are the main reason.

Taking energy prices and reduced energy expenditure into account, cost-effectiveness is completely turned around. From this perspective, the most cost-effective refurbishment then can be made in base buildings A, D and G. All others are also cost-effective (i.e. negative cost in Figure 10), but A, D and G are the ones that yield the greatest net financial benefit for each kWh heating energy saved over the lifetime of the measures. In high-rise building A, representative of warm climate EU15 countries, the large net benefit is caused by a combination of the highest heating energy prices (electricity being the main fuel), relatively low investment cost and a poor initial energy efficiency standard. For base buildings D and G – moderate and cold climate EU15 countries – the net benefit per kWh saved is primarily due to high energy prices, but also a result of fairly poor initial standards for base building D and the cold climate of base region G respectively.

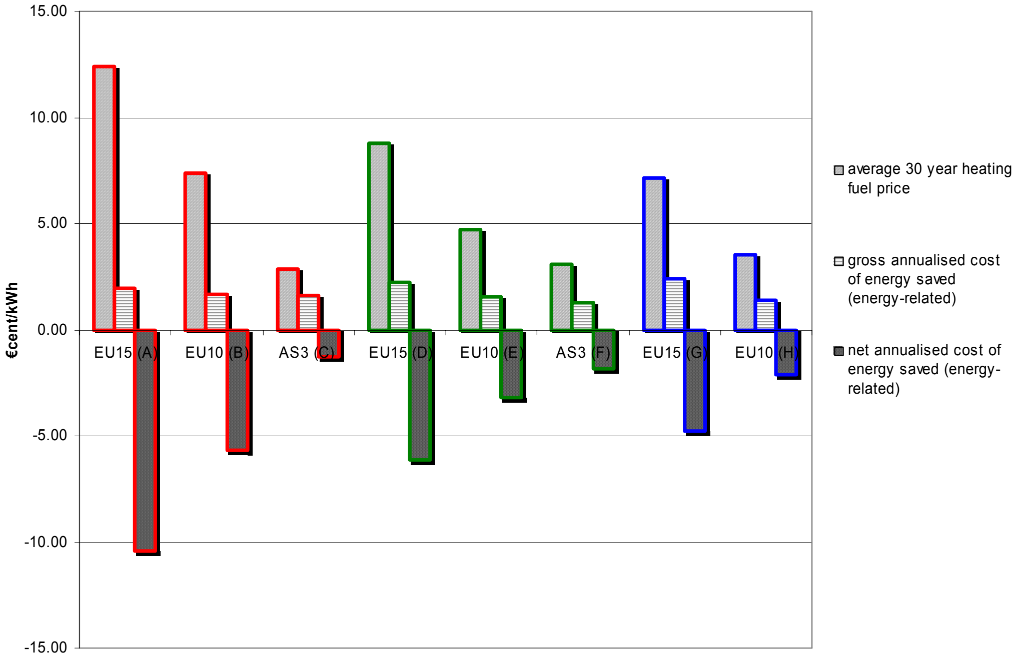
Figure 10:
Energy Prices and Cost of Energy Saved



Returning to buildings C, E, F and H, there is a substantially lower net financial benefit when taking energy prices and reduced energy expenditure into account. Despite low investment costs, these base buildings now yield less cost-effective energy savings than the other buildings because of the very low heating energy price in each of these base regions. Figure 10 also shows the net annualised cost of energy saved in the case of carrying out energy efficiency improvements as a separate retrofit rather than being integrated into the refurbishment process – which would reduce cost-effectiveness all round. Only base buildings A, D and G would still yield a net financial gain under this scenario.

Energy price rises have assumed to be uniform across all base regions at 1.5% annually in real terms across all base regions over the lifetime of the energy saving measures. However it can be argued that, given the eventual liberalisation of the energy markets and the removal of state subsidies in EU10 and AS3 countries, this rate is likely to be exceeded in this group of base regions, investment in which may then yield larger financial gain. Figure 11 illustrates a conceivable scenario where energy prices in EU15 countries rise by 1.5% a year as before, but by 3% annually in EU10 and AS3 countries. It is clear that the cost-effectiveness increases for these base buildings, but is still well behind the EU15. This poses deeper questions about likely energy price rises in these countries, and how these will compare to the old Member States.

Figure 11:
Energy Prices and Cost of Energy Saved assuming 3% Annual Increase in EU10 and AS3 Prices



Under the baseline scenario[28], using simple payback time as the indicator of cost-effectiveness – calculated by offsetting the present total (*not* annualised) investment cost against the value of energy savings as illustrated in Figure 12 – there is more visible net benefit[29] for every base building because it is (in most cases substantially) less than the economic lifetime of 20 years assumed for the shortest-lived measures.

Figure 12 also shows that simple payback of 20 years is (in some cases substantially) exceeded for buildings C, F and H – AS3 and cold climate EU10 countries – if energy efficiency improvements are carried out as a separate retrofit. For comparison, the simple payback times for both energy-related investment and retrofit cost are shown assuming a 3% annual price rise in EU10 and AS3 countries. For buildings C, F and H, this reduces simple payback for the assessed measures in a retrofit context to between 15 and 20 years.

Simple payback is only applicable as a measure of cost-effectiveness if the investment cost can be paid in total at the point of refurbishment, an option that is very rarely financially feasible for owners or occupiers. This strongly supports the argument in favour of public subsidy or grant support for energy efficiency improvements.

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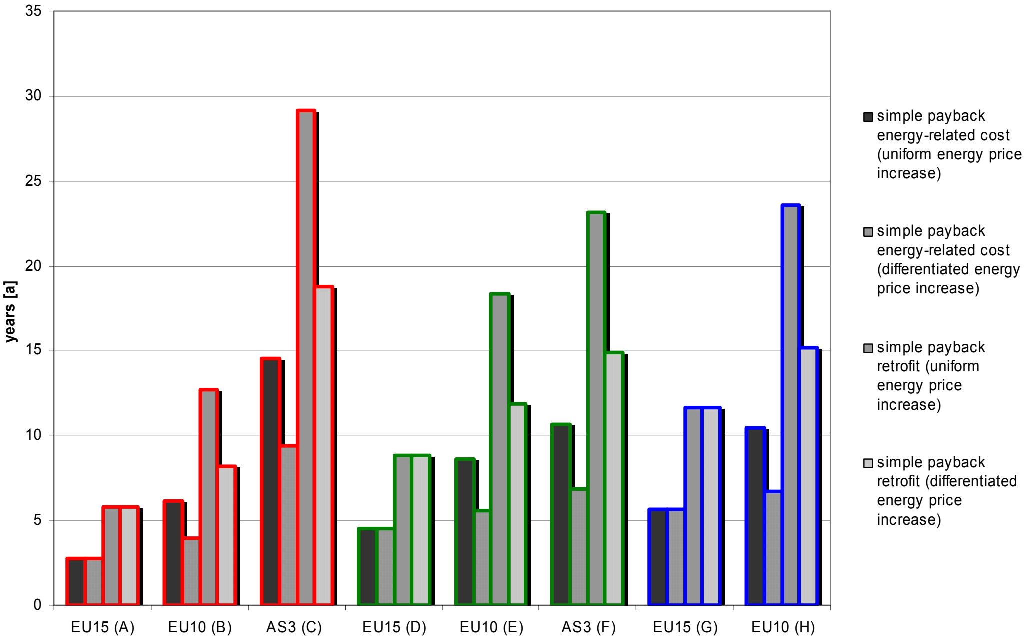
[28] Energy-related investment cost, uniform 1.5% energy price rise.

[29] Compared to using annualised investment cost.

Figure 12:
Simple Payback, for Integration into Refurbishment and Separate Retrofit



Crucially, whichever methods of financing the requisite investment are considered, the investment cost needs additionally to be balanced against wider benefits – especially avoided CO_2 emissions (see below), but also (see section 3) deferred or avoided investment in energy supply infrastructure, the possibility of job creation and the improvements in comfort and wellbeing to which energy efficiency in the refurbishment of high-rise residential buildings can contribute.

CO_2 Savings

Figure 13 shows the CO_2 savings achievable in each base building m^2 per year as a result of the energy efficiency improvement packages. The main determinant apart from the achievable energy saving for each building is the CO_2 emissions factor per kWh.

The cost of CO_2 mitigation cannot be balanced against the benefit of households' reduced energy expenditure[30] because households do not formally or directly appropriate the benefits of reduced CO_2 emissions. In a formal sense, governments stand to gain from CO_2 mitigation as this contributes to their greenhouse gas emissions reduction objectives. For governments, reduced CO_2 emissions should only be balanced against the cost of the investment. The CO_2 mitigation cost is illustrated in Figure 14, which shows that it is lowest for base buildings C, E, F and H (i.e. in EU10 and AS3 countries apart from Cyprus and Malta).

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[30] This has been calculated for individual base buildings in section 2.4.

Figure 13:
CO_2 Savings per m^2 per Year

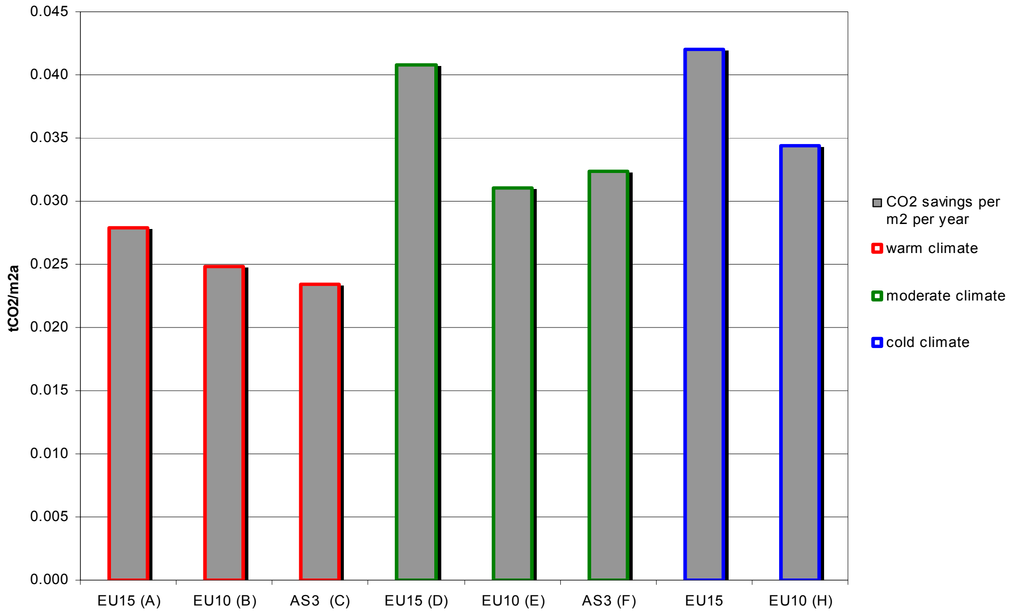
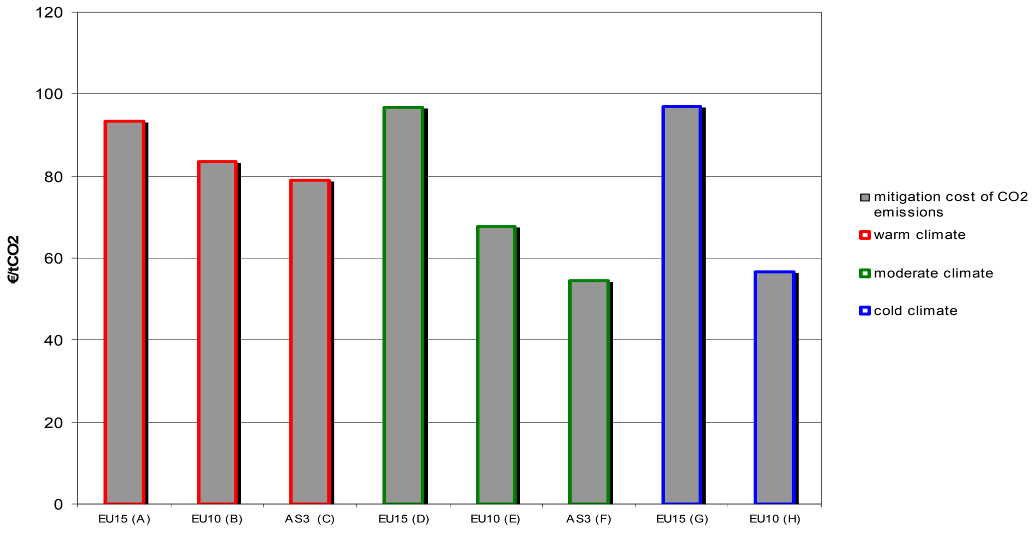


Figure 14:
CO_2 Mitigation Cost



Ideally, for CO_2 mitigation that is the result of energy efficiency improvement, reduced energy subsidy expenditure should be taken into account. The IEA has defined energy subsidies as "*any government action that concerns primarily the energy sector that lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers*"[31]. Furthermore, any

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[31] IEA (2001b)

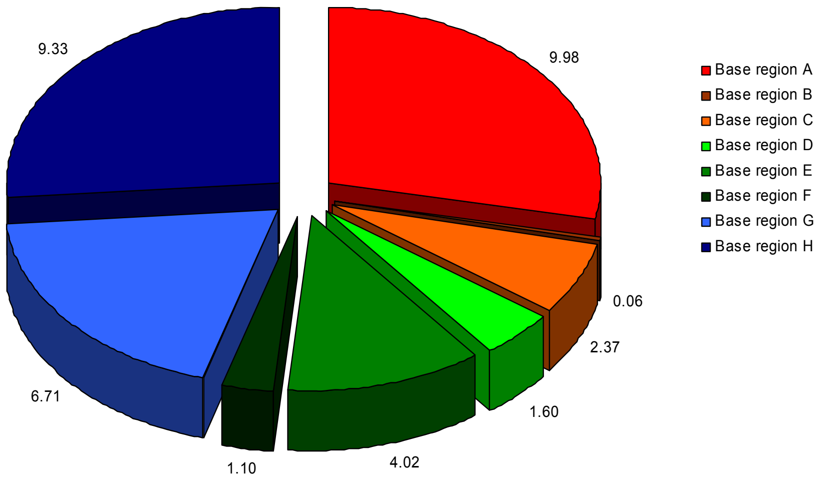
government attempt at internalising a positive externality of energy by reducing prices, as well as a failure to internalise negative externalities by not increasing the energy price can be considered a subsidy.

In EU10 and AS3 countries, in particular in Central and Eastern Europe, energy subsidies – in particular of the price paid by consumers – are likely to be relatively high, in particular because the energy market liberalisation process has not developed as far as in EU15 countries (see section 4.2.1). Only rough estimates of the levels of subsidies exist; in CEE EU10 and AS3 countries subsidy may lie between one third and one half of the energy price paid by consumers. This implies that as long as these subsidies exist, actual CO_2 mitigation cost in these countries is even lower than in Figure 14, widening the gap between these and EU15 countries.

2.5.2. Stock-wide, by Base Region

With respect to overall CO_2 emissions from high-rise buildings, there is scope for substantial reductions. Figure 15 illustrates the annual CO_2 savings possible from the high-rise stock according to the response of European Housing Ministries to the VROM-commissioned survey, based on their estimates of energy saving potential. As stated before, this potential is distinct from and lower than that identified in the modelling of individual base buildings, because a stock-wide assessment does not assume that all high-rise buildings can be refurbished to the degree assumed for an individual base building.

Figure 15:
CO_2 Savings Potential according to National Housing Ministries [$MtCO_2$]



The highest energy saving potential is in Eastern Europe; 39% in base region E and 34% base region H. Europe-wide, the energy saving potential is 28%, implying a reduction of Europe’s total final energy demand of 1.5%, and a corresponding approximate emissions reduction of 35 $MtCO_2$.

2.5.3. Key Points

- The achievable energy savings are substantial, ranging from 70% to 80% of heating demand.
- Energy prices are much higher in EU15 countries than in EU10 and AS3 countries.
- The required investment in energy efficiency improvement is lowest in EU10 and AS3 countries.
- Carrying out energy efficiency improvements as separate retrofit rather than as part of general refurbishment costs approximately twice as much.
- Taking reduced energy expenditure for households into account, there is a net benefit as a result of investment for all base buildings; the net benefits are highest in EU15 countries.
- *Net* CO_2 mitigation costs (i.e. after taking reduced household energy expenditure into account) are lowest in EU15 countries; more importantly, from a policy-maker's perspective, *gross* CO_2 mitigation costs are lowest in EU10 and AS3 countries.

3. WIDER BENEFITS OF ENERGY EFFICIENCY INVESTMENT

The benefits of investment in energy efficiency do not limit themselves to reductions in energy expenditure and reduced CO_2 emissions. Any thorough approach to assessing the cost-effectiveness of energy efficiency investment must also consider wider benefits and attempt to incorporate these into the decision-making process. It is possible to differentiate between different kinds of wider benefits, and here we describe – as far as possible in the context of high-rise residential buildings – the wider technical/financial benefits, wider environmental benefits, employment, and benefits to residents' comfort and wellbeing.

3.1. **Associated Technical and Financial Benefits**

It is important to remember that most of the countries considered by this project have privatised and liberalised their electricity supply industries to varying extents and along different vectors; this is the complex context in which we attempt to describe the range of potential benefits arising from avoided investment in energy supply infrastructure. Whilst a thorough assessment of these benefits could only be achieved by detailed nation-specific investigations, here we qualitatively describe generic benefits which might be found, to greater or lesser degrees, in any typical supply system.

3.1.1. Distribution Network Investment Deferral

The maintenance of distribution networks is the responsibility of distribution network operators (DNOs). In liberalised and unbundled energy industries these market actors depend upon maintaining system integrity for their revenue; this is, therefore, their primary interest. Furthermore, DNOs have a corresponding interest in reducing capacity strain which is commonly the cause of supply interruptions.

Investment in distribution infrastructure has generally been maintained since privatisation because of the reliability-based revenue stream. However, due to extraneous system developments such as decentralisation of power production (whereby generation assets are connected directly to the distribution network as opposed to the high-voltage transmission grid), there is increasingly fractious debate over which actor (DNO/generator) pays for local grid reinforcement. These debates frequently lead to prolonged inaction and even evasiveness about the location of network 'pinch-points' in a form of industrial brinkmanship, from which the end result can ultimately be system breakdown and outages for consumers.

Reduction in demand is a comparatively obvious solution to many of these problems. High-rise buildings are connected directly to the low-voltage distribution network, whilst high-rise estates (depending on size) might be connected to the high-voltage distribution network via a transformer. These constitute relatively significant draws on local supply, and any reduction in the size of these loads will reduce or defer the need for asset upgrading in local distribution wires, connection points and power conditioning equipment.

3.1.2. Generation Capacity Investment Deferral

Demand reductions from electricity consumers directly decrease loads for generators. This can yield benefits in both 'modern', privatised markets where generation capacity strains are present as well as CEE markets with ageing generation portfolios.

In countries with modern generation assets competition and falling electricity prices have created a situation whereby generation companies are increasingly risk-averse and less inclined to invest in new capacity. Combined with other factors such as a widespread ageing of the generation fleet (especially coal and nuclear assets), marginal surplus capacity is being eroded and supply failures are becoming more prevalent. In fully privatised markets investors prefer small to medium scale generation plant which can be brought on line relatively quickly, for significantly less capital costs than large centralised plant, and which have payback periods measured in years instead of decades.

Generation capacity shortages are an immediate concern for any government because of the vital and unique role electricity supply plays in any nation's welfare and economy. Where rapid privatisation and competition has reduced total supply capacity, demand side energy efficiency is a low-cost option for safeguarding supply when private sector motivation to invest in new capacity is deficient.

In countries with ageing generation assets, private generation companies often lack the resources required to bring new plant online and keep pace with demand. In such instances, demand reductions offer a partial, short-term solution, allowing for the extended maintenance of system integrity and the deferment of costly capacity investment.

3.1.3. Increased System Reliability

In modern electricity markets the competitive privatised generation sector has produced a number of both positive and negative effects. Where competition has been installed electricity prices have usually been driven down. This trend has reduced profit margins for generators, and many have resorted to mothballing their unprofitable 'spinning reserve'[32]. This situation increases the risks of shortages especially at peak demand periods.

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[32] This is surplus capacity, which is kept online but at the lowest possible output, and which can be brought up to full capacity when required at short notice.

As has already been alluded to, system reliability can be adversely affected by a number of factors and these vary across the EU area. Demand reduction is perhaps the only single measure that can offer a potential solution (at least in the short term) to all factors adversely affecting supply reliability. Furthermore it can do so without the need for excessive capital costs, which are frequently the critical factor in the feasibility of new energy projects.

3.1.4. Resource Conservation and Reduced Fuel Requirements

Resource conservation is a key goal of any nation, and this is especially true of those nations that are heavily dependent upon imported fuels. As EU-sourced fuel reserves decline, the proportion of imported fuels is set to rise. Not only is the importation of primary fuels comparatively expensive, but it is also not without risk. Imported supplies must first be sourced, and then transported to home markets, and this lengthy process can be interrupted by political, economic and militant action. With increasing worldwide geopolitical risks, these concerns will become more acute.

Whilst energy efficiency can be promoted in both the supply side and the demand side, there is significantly greater scope for resource conservation on the demand side (and, therefore, carbon savings), which can also be achieved at a significantly lower unit cost. Resource conservation is seen as a complimentary measure to the diversification of national fuel mixes in terms of safeguarding primary energy reserves against the risks associated with supply interruptions.

3.1.5. Reduced Price Variability

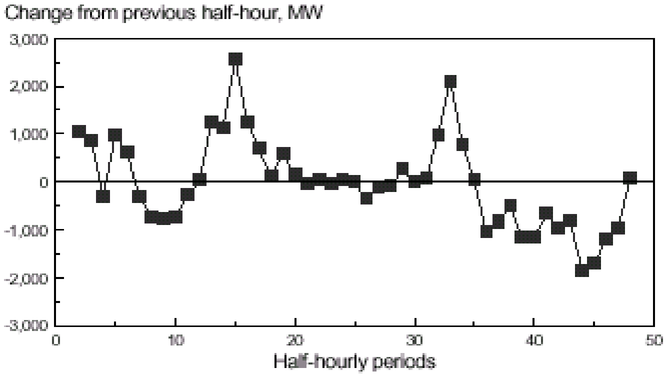
Heavy dependence upon a restricted number of fuel sources increases market susceptibility to fuel shocks. This is especially true for countries with real-time electricity trading and countries where the privatisation process has run down stored reserves or brought about a dependence on imported fuel. It should be remembered that it is not absolute fuel shortages that are a concern (at least in the short to medium term), but *economic* sources of fuel that are the priority for policy makers. Where economic fuel sources are perceived to be threatened, markets react rapidly and the resultant price spikes create unfavourable conditions for market participants. This in turn can drive market players away to more stable markets, and with them direct investment. Reducing demand by increasing energy efficiency in homes acts as a buffer against price variability and makes the market more attractive to investors. Because of the considerable proportion of total energy consumed by the residential sector, the scope for price volatility minimisation is likely to be significant.

3.2. Associated Environmental Benefits: CO_2 Savings from Reduced Generation Load

CO_2 savings are intrinsically linked with demand reductions at the most basic level, i.e. if you generate less, less CO_2 is produced. This relationship is well documented and is being pursued by Member States already to varying degrees.

What is also significant is the fact that base load demand particularly is most influenced by demand side energy efficiency measures. Heating especially is a predictable load and so a country's control and despatch system will bring (usually large) generation assets online in order to meet this demand. These power stations tend to be coal, nuclear or oil-firing assets (peak demand tends to be met by comparatively clean gas-fired or large-scale hydro plants which can be brought online or scaled up quickly). As a result, and with the exception of nuclear assets, base load is traditionally supplied by the most polluting forms of fossil fuel generation. It is this load that demand reduction measures such as those considered in this project will specifically alleviate, and which will therefore realise the most significant carbon savings.

Figure 16:
Typical half-hourly Changes in Demand Profile



The diagram above illustrates how residential demand can vary from an 'average' or base level on a typical winter day in England. To some extent these fluctuations are predictable, but not entirely. Below zero, base load generators would normally meet the generation requirement – and these would typically be coal, nuclear or oil-firing power stations. The demand load would be mostly heating requirements, and it is this demand that the energy efficiency packages envisaged in this project would alleviate. The area above the zero line indicates peaking demand, produced mainly from household applications such as televisions and kettles. This demand is normally met by relatively clean gas-firing power stations. The generation profile thus aligns favourably with residential energy efficiency packages from a carbon reduction perspective.

3.3. **Associated Employment Benefits**

Previous work on the employment impacts of energy efficiency investment programmes in EU countries suggests that in the majority of cases, energy efficiency investment increased employment. Key findings of a comprehensive study by the Association for the Conservation of Energy[33] were:

- Of 44 case studies carried out in 9 EU10 countries, 38 were found to have generated additional employment.
- Per million Euros (MEuro) of total expenditure (both government and private) energy efficiency programmes typically resulted in eight to 14 additional person-years of employment.
- In the residential sector, employment gains were typically higher than in other sectors, although the investments were less cost-effective in terms of energy savings than in other sectors.
- Many of the programmes identified a majority of new employment in manual occupations – this was especially true of the residential sector.
- The employment effect of energy efficiency programmes is almost always positive, and the jobs are often in sectors, locations and skill groups that are prioritised in employment policies. However, the number of jobs created is typically small compared to the size of the investments. Therefore creation of employment will be a desirable side effect of the programmes, but should not be the primary objective.

This picture is almost entirely positive, and it appears that public or private energy efficiency programmes both can stimulate beneficial local and national job creation. The fact that the majority of job creation in the residential sector was manual employment is also advantageous as this particular skills base is prevalent in CEE nations where, coincidentally, high-rise buildings much larger proportions of the housing stock than in most other European countries.

The study found three main components to the employment impact of energy efficiency investment programmes. First is the direct employment resulting from the manufacture, installation and operation of energy efficiency products and processes, as well as from the management of these activities. Second is the counterbalancing negative effect on employment in the energy supply industries resulting from concomitant reductions in energy demand[34]. And third, there is secondary employment generation or loss. This results from increases or decreases in spending in sectors with different labour intensities. For example, energy consumers who experience energy bill reductions will have increased income available

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[33] Association for the Conservation of Energy (2000) *National and Local Employment Impacts of Energy Efficiency Investment Programmes – Summary Report*, London, SAVE contractXVII/4.1031/D/97-032.

[34] Although it proved difficult to quantify this effect – many European supply industries are in a state of considerable flux at the present time, with significant associated shifts in employment which complicate the picture.

for other spending. Furthermore, government spending may be altered by the provision of grants or subsides, tax receipts on energy and altered unemployment benefit bills.

The investigation also found some evidence of a dichotomy between the effects of unilateral (national) and EU-wide investment in energy efficiency programmes on employment. Macro-economic modelling suggested that where countries initiate energy efficiency programmes there can be some job losses at the EU level in the short term. However at the national level negative outcomes are very rare in terms of employment, and in the longer term the outcome is always positive. This would suggest that coordination of energy efficiency implementation at the national level should be a priority, and the modelling suggested that EU-wide policy adoption produces greater gains in employment and larger reductions in energy consumption than in unilateral scenarios, and that these gains were also more persistent.

3.4. Associated Comfort and Wellbeing Benefits

It is well accepted that there is an intimate relationship between housing and residents' physical and mental health and wellbeing. However, epidemiological and longitudinal studies are few and far between. This is mostly due to the multitude and dynamism of housing factors – and of course non-housing factors – that can affect health and the resultant difficulty in isolating factors to assess housing dose-response relationships. The majority of studies in this area have based their research on residents' self-reporting of their housing-related health status. Consequently, it has so far not been possible to quantify the contributions that energy efficiency improvements can make to residents' health.

The WHO has recognised the need for stronger and consistent evidence of the links between housing and health and has been undertaking a study involving eight countries with the aim of developing measurable housing and health indicators[35]. The results of a pilot survey of housing and health in panel block buildings – i.e. large multi-family, in some cases high-rise buildings – in former East Germany, Lithuania and Slovakia were published in 2003[36]. The survey comprised 259 flats and 601 residents, assessing their perception of their own health. It surveyed both un-refurbished and refurbished situations, including control groups of residents for the latter. In line with previous experiences, it proved difficult to identify any aspect of the housing conditions having a clear overall effect on residents' health, although the fact that it found residents' satisfaction to have improved with refurbishments "raised expectations that housing improvements can lead to better health"[37]. Given the area it covered, its findings are particularly important to this project.

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[35] See http://www.euro.who.int/Housing/Activities/20020711_1.

[36] Bonnefoy *et al* (2003)

[37] ibid.

The key issues identified in panel block buildings with the ability to adversely affect residents' comfort and wellbeing were small dwelling size, air quality, temperature and draught, noise exposure and the use of harmful building materials[37]. Energy efficiency measures and improvements can directly improve three of these. First, air quality can be improved through a combination of improved building air tightness and an appropriate ventilation strategy. Second, comfortable and consistent temperatures can be more easily achieved and draughts eliminated through a combination of heating (control), building fabric and ventilation improvements. Third and finally, insulation measures and window replacements reduce noise exposure.

As stated above, the WHO survey asked residents whose panel block dwellings had undergone refurbishment their subjective views of their comfort and wellbeing. This methodology meant meaningful associations could be inferred, but *not* that causal links between refurbishment and stated improved comfort and wellbeing could be established.

Table 18 illustrates the WHO's statistically significant findings yielded by the survey data.

Table 18:

WHO Survey: Statistically Significant Results (**=highly significant, *=significant[38]) [37]

	Existence of ventilation system	Satisfaction with ventilation system	Suffering from chronic disease	Mould growth
Air quality perception	**	**	*	**
	Temperature problems in transient season	Gas stove/oven	No exhaust system in kitchen	Room without adjustable heating
Mould growth	**	**	**	**
	Temperature problems in transient season	Temperature problems in summer season	Condensation signs at windows	Problems with humidity
Asthma/allergic symptoms	**	*	**	*
	Temperature problems in transient season	Air quality perception	Draught problems	Mould growth
Acute respiratory diseases	**	**	**	**
	Exposure to ETS in bedrooms	Air quality perception	Satisfaction with noise conditions	Temperature problems in winter season
Health perception	**	**	**	**
	Good sound insulation quality	Less problems to fall asleep	Frequency of noise exposure	Temperature problems in winter season
Good mental health	**	**	*	*

It is clear that the survey results show a wide range of associations that between self-reported health and living conditions in panel block buildings can be reliably made. While the identified associations are not causal, it is clear that energy saving measures, in combination with appropriate ventilation strategies, contribute directly to (improving the) issues illustrated by the shaded cells in

Table 18, and so clearly have the potential to contribute to improving residents' comfort and wellbeing.

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[38] Two stars means statistically significant at the 99% confidence level, one star implies statistically significant at the 95% confidence level.

4. OPPORTUNITIES FOR AND BARRIERS TO ENERGY EFFICIENCY INVESTMENT

Incorporating energy efficiency into the refurbishment of high-rise residential buildings presents an opportunity to address far-reaching economic, social and environmental sustainability objectives. These three aspects of sustainable development's so-called 'triple bottom line' are all supported by the contributions that improving energy efficiency can make to energy security, community development and regeneration, and mitigation of climate change. This is the driving force behind the arguments in favour of energy efficiency investment, the specific relevance of which to the high-rise housing stock in Europe has been elaborated upon in sections 2 and 3. This section identifies and assesses political and institutional, financial and economic, legal, and capacity and social opportunities and barriers that energy efficiency investment in high-rise buildings is faced with in Europe. The issues covered are broad, and the list is certainly not exhaustive, but in order to ensure knowledge gaps were closed and the most significant opportunities and barriers were included and drawn together, a formal brainstorming session was held with representatives of EuroACE members. The subjects covered are intended to inform the reader's view as well as this project's conclusions and recommendations in section 6.

4.1. **Political and Institutional Opportunities and Barriers**

4.1.1. Framework and Background Conditions

Political and institutional framework conditions at a European, base building region, national and local level give rise to a wide variety of opportunities and barriers to energy efficiency refurbishment of residential high-rise stock. The existing structures of government departments and their responsibilities, in particular whether the areas of housing, energy, regional development and the environment are integrated or coordinated, may be a significant indicator of the degree to which refurbishment objectives exist or can be successfully achieved. Table 19 lists the European housing ministries and which of the other areas energy, regional development and environment have been integrated or are covered by separate government departments[39]. It is important to note that even nominally fully integrated ministries may still face internal difficulties in achieving sustainable refurbishment objectives.

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[39] A "✓" denotes that the ministry responsible for housing is responsible for that sector.

Table 19:
Housing Ministries and Related Responsibilities

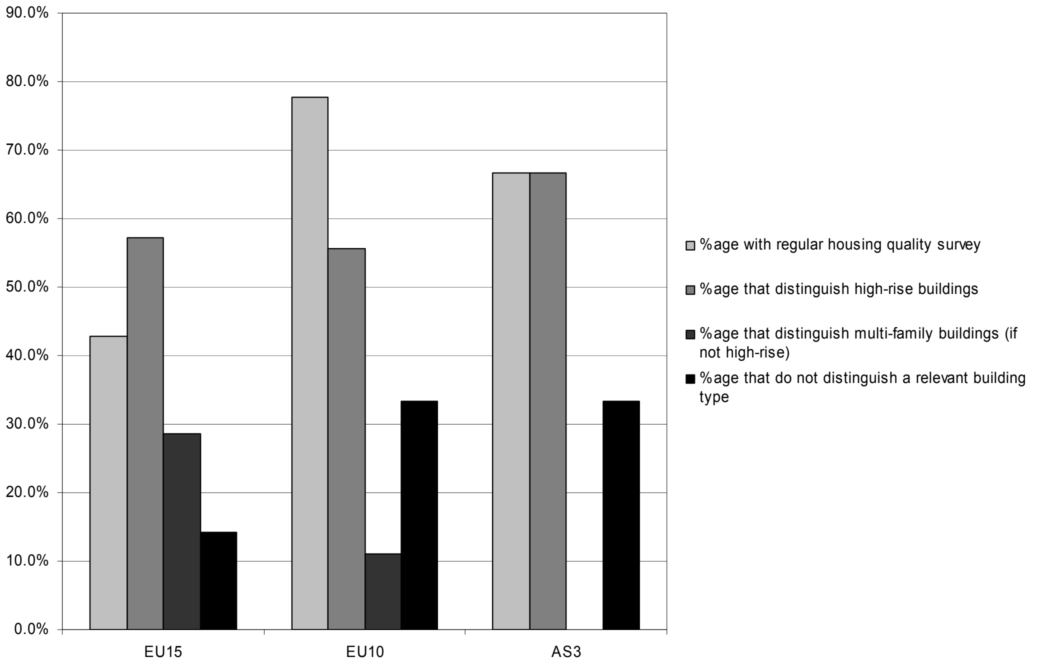
	Ministry responsible for housing	Energy	Regional development	Environment
Austria	Federal Ministry of Economy and Labour	✓	Federal Ministry for Agriculture, Forestry, Environment and Water Economy	Federal Ministry for Agriculture, Forestry, Environment and Water Economy
Belgium	Ministry of Finance	Ministry for Economy, SMEs, Self-employed and Energy	devolved according to Belgium's federal structure	Ministry of Public Health, Food and the Environment
Bulgaria	Ministry of Regional Development and Public Works	Ministry of Energy and Energy Resources	✓	Ministry of Environment and Water
Cyprus	Ministry of the Interior	Ministry of Commerce, Industry and Tourism	✓	Ministry of Agriculture, Natural Resources and Environment
Czech Republic	Ministry for Regional Development	Ministry of Industry and Trade	✓	Ministry of the Environment
Denmark	Ministry of Economic and Business Affairs	✓	Ministry of the Interior and Health	Ministry of the Environment
Estonia	Ministry of Economic Affairs and Communications	✓	✓	Ministry of the Environment
Finland	Ministry of the Environment	Ministry of Trade and Industry	Ministry of the Interior	✓
France	Ministry of Employment, Labour and Social Cohesion	Ministry of the Economy, Finance and Industry	Ministry for Infrastructure, Transport, Spatial Planning, Tourism and the Sea	Ministry of Ecology and Sustainable Development
Germany	Ministry of Transport, Building and Housing	Ministry of Economics and Labour	✓	Ministry for the Environment, Nature Conservation and Nuclear Safety
Greece	Ministry for the Environment, Physical Planning and Public Works	Ministry of Development	Ministry of the Interior, Public Administration and Decentralisation	✓

Hungary	Ministry of Economy and Transport	Ministry of Economy and Transport	Ministry of Agriculture and Regional Development	Ministry of Environmental Protection
Ireland	Department of the Environment, Heritage and Local Government	Department of Communications, Marine and Natural Resources	✓	✓
Italy	Ministry of Infrastructure and Transport	Ministry of Productive Activities	Ministry of Infrastructure and Transport	Ministry of the Environment
Latvia	Ministry of Economics	✓	✓	Ministry of Environment
Lithuania	Ministry of Environment	Ministry of Economy	Ministry of the Interior	✓
Luxembourg	Department of Housing	Ministry of Economy and Trade	✓	Ministry of Environment
Malta	Ministry for the Family and Social Solidarity	Ministry for Resources and Infrastructure	✓	Ministry for Rural Affairs and the Environment
Netherlands	Ministry of Housing, Spatial Planning and the Environment	Ministry of Economic Affairs	Ministry of Economic Affairs	✓
Poland	Ministry of Infrastructure	Ministry of Economy and Labour	Ministry of Economy and Labour	Ministry of the Environment
Portugal	Ministry for Cities, Local Government, Housing and Regional Development	Ministry of Economy and Employment	✓	Ministry of the Environment
Romania	Ministry of Transport, Constructions and Tourism	Ministry of Economy and Commerce	Ministry of Administration and Interior	Ministry of Environment and Waters Management
Slovakia	Ministry of Construction and Regional Development	Ministry of Economy	✓	Ministry of Environment
Slovenia	Ministry of the Environment and Spatial Planning	Ministry of the Economy	Ministry of the Economy	✓
Spain	Ministry of Housing	Ministry of Industry, Tourism and Trade	Ministry of Public Administration	Ministry of the Environment

Sweden	Ministry of Sustainable Development	✓	Ministry of Industry, Employment and Communication	✓
Turkey	The Ministry of Public Works and Settlement	Ministry of Energy and Natural Resources	Ministry of Interior	Ministry of Environment and Forestry
United Kingdom	Office of the Deputy Prime Minister	Department of Trade and Industry	✓	Department of Environment, Food and Rural Affairs

Closely related is the question over whether there exists the institutional intent and capacity necessary to achieve refurbishment objectives. Are procedures in place to collect, collate and interpret data on the housing stock, including the running of demonstration projects, dissemination of best practice knowledge, and setting of benchmarks or minimum standards for energy efficiency, products and workmanship?

Figure 17:
Existing Institutional Data Collection Capacity[40]



Where such procedures exist – see Figure 17 – are high-rise buildings being distinguished or classed as a different category necessitating different approaches? Furthermore, do mechanisms exist to deliver new regulations and financial incentives? At a European level, there exist a number of demonstration and best

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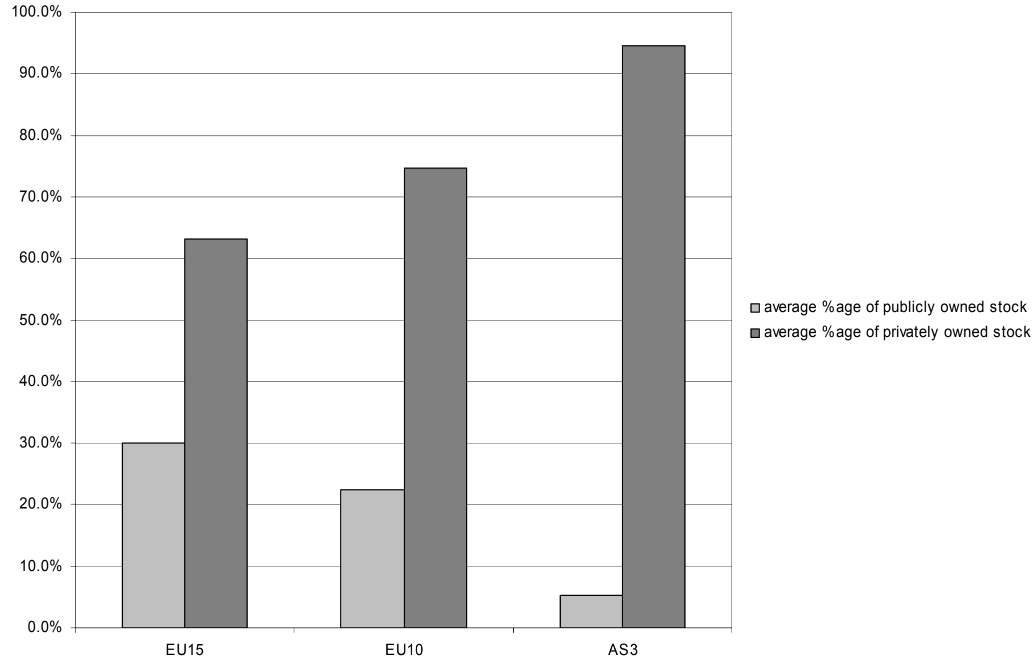
[40] Based on survey data underlying PRC Bouwcentrum International (2005).

practice programmes and resources on the refurbishment of high-rise or multi-family buildings, some of which focus especially, but not exclusively, on energy efficiency. The most important are OPET Building[41], SUREURO[42] and LOCOSOC[43].

The degree of housing privatisation can be an important opportunity or barrier to refurbishment. Generally, public ownership would allow for a greater degree of control, making it easier to coordinate and carry out decisions on refurbishment, in particular with respect to the incorporation of energy efficiency measures.

Figure 18:
Ownership of Housing Stock[44]



Given the rapid transformations in ownership structure and associated institutional change in particular in Eastern Europe – now with the lowest proportion of publicly owned stock as illustrated by Figure 18, in strong contrast to pre-1990 era – existing housing stock refurbishment strategies are unlikely to be very well suited to or experienced with the current situation. Strategies may have to be developed from scratch. Achieving the refurbishment of privately owned stock, especially privately let stock, may have to rely on greater economic incentives, and also relies on public money. It may also prove harder to achieve resident consensus. Public private partnership (PPP) approaches could hold much promise for refurbishment

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[41] The European Network for the Promotion of Energy Technologies in the Building Sector (http://www.opet-building.net)

[42] Sustainable Refurbishment Europe (http://www.sureuro.com)

[43] *LOw COst SOCial housing* (http://www.locosoc.info)

[44] Based on survey data underlying PRC Bouwcentrum International (2005); remaining percentages have been classed as "Other" in the survey.

objectives, though experiences to date are thin on the ground as is knowledge of drawing up successful PPP contractual frameworks, particularly but not only in the new Member and Accession States.

Existing institutional practices may or may not prove conducive to the development of new policy instruments to promote energy efficiency investment. Standards of auditing procedures, transparency and formal accountability will affect the effectiveness of any instruments promoting energy conservation in high-rise buildings.

Membership of the EU can prove to be an obvious opportunity for energy efficiency in the refurbishment of high-rise buildings, entailing as it does the various financial and legal drivers and prospects (see sections 4.2 and 4.3).

4.1.2. Politics

Political processes and priorities will co-determine the willingness of governments to promote energy efficiency investment. There may for instance be a stated preference or policy of demolishing existing high-rise buildings at the appropriate point in their lifetimes and pursuing a concurrent new build strategy. Indeed, many governments, especially in Western Europe, have regarded the construction of high-rise residential buildings as a mistake of housing policy. In the UK, for example, a large proportion of the high-rise stock has been torn down. This has been as much a result of poor construction quality as it has been of the pockets of social deprivation that developed on high-rise estates[45]. Though the concept of high-rise living is experiencing a revival, not least due to the potential contribution to the high-density urban planning paradigm, this has mainly been in the form of new design and construction[46]. Where the issue of embodied energy has not been incorporated into decision making over whether to refurbish or build anew, this may present a barrier, although the potential for reusing materials from buildings earmarked for demolition must also be considered.

The definition of high-rise residential buildings defines the scale and the spatial distribution of the energy-saving potential to a large degree. The definition used by this report and others, more than four storeys high, results in a large and important but also highly diverse sector of the housing stock. Existing, country-specific definitions of high-rise stock may provide an opportunity for tailoring policy instruments more closely to regional needs.

Many policy options to promote investment in energy efficiency may prove politically difficult to bring in or be potentially unpopular, especially where compulsion or taxation is necessary. This barrier, in combination with elections or competing priorities, results in a compounded problem that may weaken the political resolve to bring in improvements. In this context, an important opportunity exists to make

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[45] BBC News (2000)

[46] Walker (2004)

less popular policy options more acceptable by the public sector practicing what it preaches or leading by example.

4.2. **Financial and Economic Opportunities and Barriers**

4.2.1. The 'real' Cost of Energy

As identified in section 2.5, energy prices are a key determinant of the cost-effectiveness of investment in energy efficiency, and with respect to high-rise buildings in particular, there are a number of barriers related to the price of energy. Most salient is the fact that in the EU10 and AS3 countries in particular, energy prices are so low, due to subsidy, as to make investment in energy efficiency a far less attractive prospect than in EU15 countries, due to the increased payback time. The opportunity to overcome this barrier arises with the requirement of two European directives for all Member States to fully liberalise their gas and electricity markets by mid-2007[47]. Nevertheless, in high-rise buildings in particular, because they are more frequently connected to district heating networks than other forms of housing, the tariff structure for heat from such networks creates a further barrier and disincentive to invest. Most district heating companies are locally or regionally based and charge for their services at a flat rate or independent of the amount of heat consumed. This system intrinsically does not place any incentive to save energy on the householder. Nevertheless, there may be an incentive to save energy, faced in principle by the heat supplier – this may be the heat producer, or the local authority, which frequently acts as an intermediary between producers and end-users. The incentive lies in the potential for charging the same tariff and providing the same level of service, but doing so more efficiently and increasing profit margins in the case of the producer supplying or enabling a decrease in cost to the consumer in the case of the local authority supplying. Depending on the supplier and the extent of public-private partnership, this may take the form of improving generation and distribution efficiency of heating networks, but also helping fund the efficiency improvement of the end-users dwellings.

4.2.2. Economics

It is generally accepted in economic theory and supported empirically that "consumption, non-residential investment, residential investment and GDP all co-move positively"[48]. In particular, it can be argued that when the economy is stronger, this favours new construction, and when the economy is weaker, that refurbishment of housing is favoured more strongly than new build – though the refurbishment rate is likely to be higher when the economy is doing well. 'Co-movement' simultaneously implies that

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[47] Gas Directive 2003/55/EC and Electricity Directive 2003/54/EC

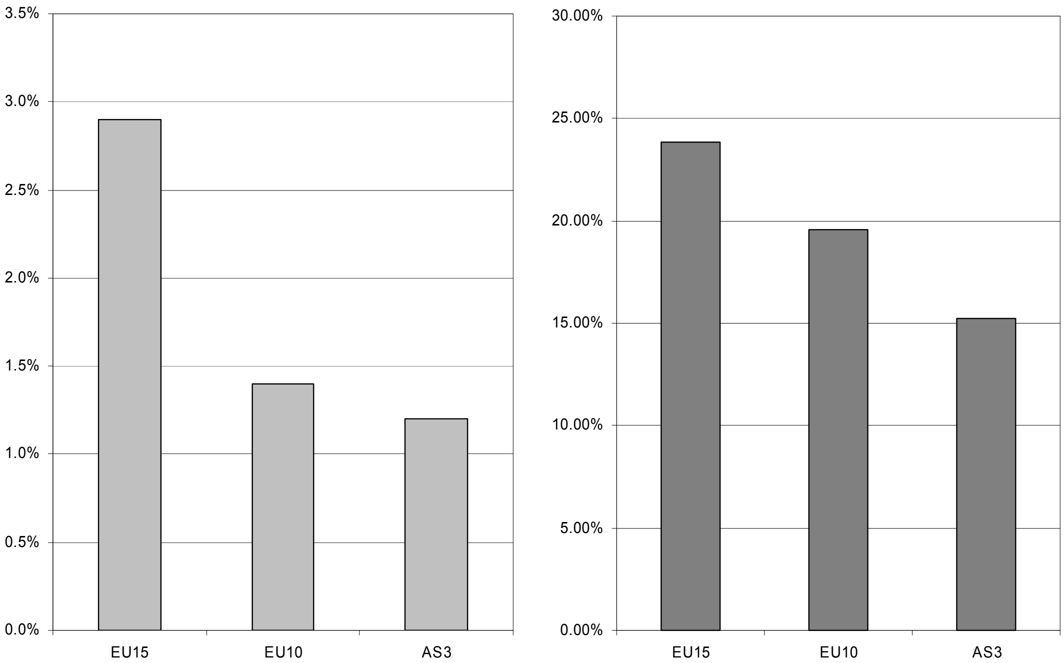
[48] Davis & Heathcote (2004)

residential investment can drive economic growth; given the constraints placed on new construction by the availability of land and the related pressures to use brown-field sites, there may be a case for developing stronger economic arguments in favour of refurbishment of existing (by implication brown-field occupying) housing stock. The high density of high-rise housing stock should mean that it ought to be favoured by such arguments.

In the context of scarce public funds, even where high-rise refurbishment can be shown to be a sound investment, there are other areas of public spending which may have lower cost-benefit ratios. In particular, but not exclusively, in the context of unaccounted for and/or less tangible benefits (e.g. job creation or comfort[49]) and costs (e.g. carbon and energy costs[50]), investment in high-rise refurbishment will have to compete with other sectors that could be (justifiably) more beneficial. Though responses were incomplete,

Figure 19 indicates the percentage of annual state budget and annual household budget spent on housing, according to the survey of European housing ministries.

Figure 19:
Percentage of State Budget and Percentage of Household Budget spent on Housing[51]



A clear pattern emerges, with respect to both state and household expenditure. EU15 have the highest percentage expenditure on housing, followed by EU10 and AS3 countries. Simultaneously, those

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[49] See section 3.

[50] See section 2.

[51] Based on survey data underlying PRC Bouwcentrum International (2005).

countries or regions expending the largest fractions also have the highest per capita GDP. This supports the link between GDP and residential investment and appears to suggest there are higher expenditure priorities in EU10 and AS3 countries compared to EU15. Furthermore, it also seems as if the amount of public funding available for housing where refurbishment of high-rise stock may be most needed is also lowest.

Additionally linked to the economy is the issue of interest rates, which in turn interacts with the cost of energy and payback times for energy efficiency investments. In addition to the political and institutional opportunities afforded with EU membership, there are potential financial and economic advantages. For the EU10 countries, joining the Euro-zone by 2006 to 2007 will ensure additional interest rate stability which should make energy efficiency investments a more attractive prospect than previously. However – and this applies particularly to lower income households and hence high-rise buildings – personal interest rates or the level of risk aversion may be so high with respect to residential investments that energy efficiency improvements are not even considered because they do not pay back quickly enough from the householder's point of view; a problem made worse by heavily subsidised energy prices. In other words, there may be a strong preference for money today over money tomorrow. Indeed, this could provide a partial explanation for the differences in housing expenditure in

Figure 19, but it also implies there are underlying social barriers to energy saving and refurbishment, some of which are explored further in section 4.4. Nevertheless, sustained economic stability can contribute to alleviating such 'internal' barriers.

4.2.3. Incentives and Funding Mechanisms

Financial incentive structures are one of the main instruments in redressing householders' unwillingness or inability to invest in energy efficiency by themselves. Their absence can obviously act as a barrier to energy efficiency investment, though financial instruments can also conflict with one another, causing counter-incentives and diminishing the effectiveness of each. The recurring theme, heavily subsidised energy prices or flat tariff energy provision – commonly faced in high-rise buildings – always diminishes the strength of any incentive to save energy directed at the householder. In the case of the private-rented sector – i.e. when the owner or investor is not also the bill-payer – the same loss of incentive applies.

Much of the immediate object of financial incentives is to overcome the difficulty of the (sometimes) initially high investment required by (energy efficiency) refurbishment. In low income households – which have a high incidence in high-rise buildings compared to other types of housing – access to mortgaged finance, often used as a funding source for refurbishment, is frequently restricted precisely because income levels are low. Specifically set up revolving loan funds or favourable building- or estate-based savings accounts for refurbishment can of course offer a way around this problem and can also be offered to owner-occupiers and landlords alike.

A common barrier to investment exists when energy efficiency is not distinguished from other goods and services in its fiscal treatment; for instance, charging a higher rate of value added tax on energy saving materials and associated labour than on energy, or taxing an increase in property value brought about by energy efficiency refurbishment. There are many ways in which such imbalances and counteracting incentives can be redressed, such as increasing the level of subsidy for individual energy saving measures as long as they are installed as a package – a non-linear subsidy like this could conceivably go above 100%. With the requirement to produce energy certificates for buildings being introduced by the Energy Performance of Buildings Directive (EPBD), new opportunities for fiscal and financial instruments to encourage energy efficiency arise. For example, property taxes could be linked to the level of energy certification achieved, even the cost of certification itself could be subsidised on the condition of particular energy-saving measures having been installed. Section 4.3.1 outlines why the EPBD provides an opportunity that is particularly relevant to high-rise buildings.

Other projects have gone into significantly more depth on incentives and funding mechanisms. The European SAVE project FRAMES[52] is at the forefront of investigating options and best practice for financial incentives for energy efficient multi-family housing refurbishment, and is a key resource and opportunity in this respect.

4.3. **Legal Opportunities and Barriers**

4.3.1. Legislative Drivers

The Energy Performance of Buildings Directive is the foremost legislative driver for improving energy efficiency in high-rise buildings at a European level. Requiring that national legislation transposing the Directive's requirements is in force by 6th January 2006, it stipulates that "whenever a building with a total useful floor area of over 1000m^2 undergoes major renovation, its energy performance [must be] upgraded to meet minimum requirements […]. These should be technically, functionally and economically feasible"[53]. Even the lowest of high-rise buildings at five storeys high is likely to exceed 200m^2 useful floor area per storey, bringing virtually all of the high-rise stock under the obligation to meet minimum energy performance requirements. These requirements are defined by individual member states, can pertain to either the building as a whole or the renovated system and components, and must be reviewed every five years to reflect technical progress. Furthermore, as discussed in section 2.1 and 2.5, it

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[52] Framework Innovations for Building Renovation: Best Practices for the Renovation of multi-family Residential Buildings built after WWII (http://www.eva.ac.at/projekte/frames)

[53] Warren (2003)

is precisely when a building undergoes major renovation that improvement of its energy efficiency is most cost-effective to undertake.

The *proposed* Energy End-use Efficiency and Energy Services Directive (ESD) stipulates that Member States must remove or amend “national legislation and regulations that impede or restrict the use of financial instruments for energy savings in the market for energy services”[54] – this would directly address some of the barriers identified in section 4.2.3. Furthermore, the ESD suggests the Member States establish funds, such as “grants, loans, financial guarantees and/or other types of financing” that “subsidize the delivery of energy efficiency programmes and other energy efficiency measures and promote the development of a market for energy services, including the promotion of energy auditing, financial instruments for energy savings and, where appropriate, improved metering and informative billing”[55]. The establishment of procedures for the latter – “improved metering and informative billing” – is a must. Stipulations like these can provide a real opportunity to improve (or create in the first place) the link between energy consumption and energy expenditure; especially important in the high-rise context here is the requirement to ensure provision of individual metering for each end-user (i.e. dwelling).

It is clear that there is potential for the EPBD and the ESD to have a synergetic effect on (the market for) energy efficiency in buildings. With the ESD progressing steadily through the legislative process, it will prove a very important opportunity to conduct research into these legislative synergies at a European level.

4.3.2. Condominium Law

The legal framework for condominiums or tenement groups in each country can prove a strong determinant of residential investment. The presence of a formal requirement for the inhabitants or owners of dwellings in a high-rise block to exist as a legally defined entity and the way in which this entity’s rights and responsibilities are defined can create critical opportunities for and barriers to residential (energy efficiency) investment. Figure 20 provides some indication of the legal frameworks present in Europe, and can thus grant insight into where the most relevant aspect of condominiums – collective responsibility for a high-rise block or estate – is prevalent.

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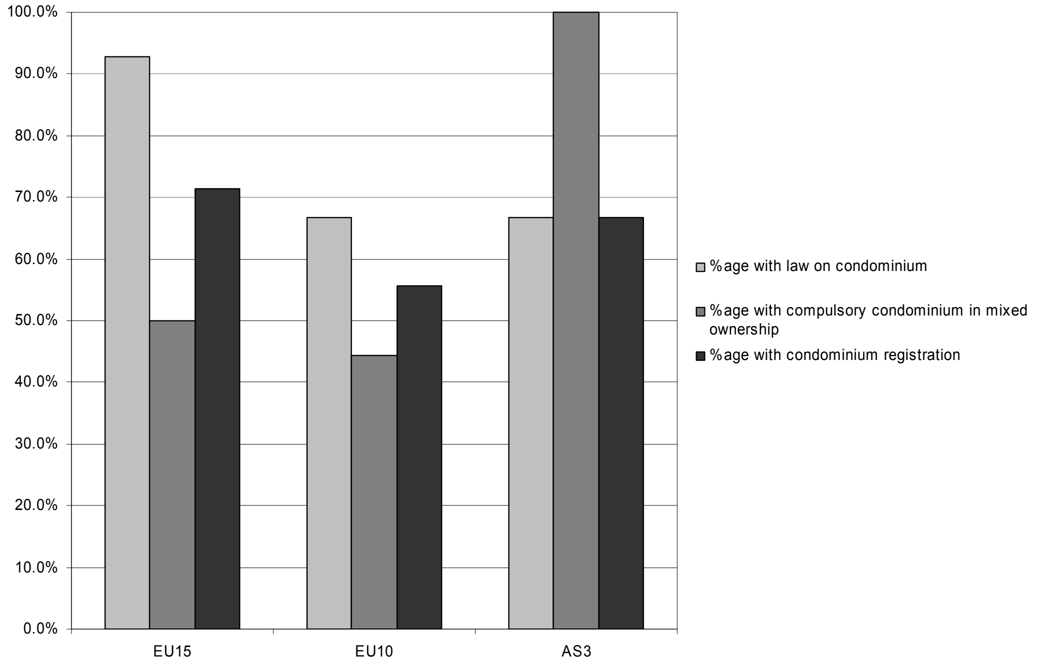
[54] CEC (2003)

[55] ibid.

Figure 20:
Prevalence of Condominium Law[56]



It appears as if the incidence of the most extensive legal frameworks is highest in EU15 countries, and one important explanation for this may lie in the higher degree of high-rise private ownership in EU10 and AS3 countries. The most significant barrier appears to be in those four EU10 countries that neither have a law on condominiums generally, nor specifically in cases of mixed ownership. Nevertheless, not having a legal framework for condominiums, while such a framework could certainly provide a good basis for collective action, does not automatically mean that it is impossible to facilitate residential (energy efficiency) refurbishment. Residents of high-rise buildings may draw up their own condominium contracts in the absence of a legal requirement to do so, or may even come to informal agreement. Still, because some residents would always be able to ‘free-ride’ on other residents’ energy efficiency investments, so creating a disincentive to invest, there is a solid argument in favour of using compulsion to ensure collective responsibility.

Condominium laws may carry their own barriers; one of the most serious may be a resident unanimity requirement for proceeding with any proposed refurbishments. Majority-voting may provide a more constructive way forward in averting worst-case situations in which a single resident may have the power to stop refurbishments everyone else can agree upon. Compulsion to save for refurbishment, using condominium law, is another option; the approach may be unpopular but is likely to be effective. In Denmark, for instance, condominiums must maintain a fund for building refurbishment that contains at

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[56] Based on survey data underlying PRC Bouwcentrum International (2005).

least four per cent of the building's value. Conceivably, opportunities exist in combining legal requirements such as this with financial or fiscal incentives linked to energy certification achieved. This may not only make measures such as this more effective, but can also act to overcome political difficulties of introducing them.

4.3.3. Other Law

Other legal frameworks have some bearing on energy efficiency investment in high-rise buildings, albeit not as directly as the issues discussed in sections 4.3.1 and 4.3.2. Planning law and powers and building control authority, often devolved to a local level, will have some jurisdiction over whether planned refurbishments are given a green light. Inclusion of energy efficiency in the refurbishment of a building, which in the case of high-rise may often entail exterior insulation and cladding, can change the building's appearance and character. Whether this is for the better or worse is usually a question of taste, what matters is whether planning rules act as an opportunity or barrier by prioritising conservation of character or conservation of energy. The high-rise blocks of the 1960s and 70s are not exempt from such protection. Trellick Tower in West London was granted the second-highest protected status for English buildings in 1998 because it is a historically significant example of Brutalist architecture.

Figure 21:
Trellick Tower, West London by Erno Goldfinger (completed 1972)

Buildings with this status cannot have refurbishments implemented which affect their character, though in the case of buildings with a lower protected status, refurbishment plans are negotiable in many jurisdictions where planning officials usually have some discretionary powers. The conclusions to be drawn are to ensure the incidence of conflicts between energy conservation and conservation generally stays low, that planning officials are provided with clear guidance to this effect, and that developers involve planning officials in the refurbishment process as early as possible to enable a constructive relationship. In the context of planning law as it applies to non-protected buildings, clear guidance must be available to planning officials on building fitness decision criteria – i.e. whether demolition or refurbishment should be the first choice. A barrier to cost-effective refurbishment may exist where a preference for demolition has been enshrined in planning law. Similarly a barrier exists when monitoring and enforcement of compliance with building regulations is poor. Building control agencies and officials need to independent, consistent, and be able to communicate credible threats for non-compliance.

Many of the impasses of planning law and building regulations can be overcome or avoided if the opportunity is taken to fully consult residents and other stakeholders, so involving them in decisions on refurbishment and compliance. This is to an extent implicit in the condominium context, but private tenants, not just owners, need to be equally involved in decisions regarding their home. The fact that there rarely is a legal requirement to do so can prove a barrier to residential energy efficiency investment. With publicly owned buildings however, consultation with stakeholders on refurbishment should be seen as a legal requirement because of the Århus Convention, which has given rise to European Directive 2003/35/EC. This Directive provides the right to public participation in environmental impact assessments amongst other processes, and requires Member States to transpose it by summer 2005.

4.4. **Capacity and Social Opportunities and Barriers**

4.4.1. Energy-use Culture

The culture of residential energy use can pose a significant barrier to achieving modelled energy savings and cost-effectiveness of residential energy efficiency investment. Residents of the lower floors of high-rise buildings serviced by district heating networks in EU10 countries for example, where measures have been installed to allow heating control of individual radiators, may continue to mitigate overheating by opening windows rather than using new TRVs effectively. Adequate marketing and energy advice tailored to suit different user-groups and lifestyles is a critical component of any energy efficiency programme and refurbishment, in particular where entirely new systems are introduced into dwellings. The installation of heating controls can also provide an opportunity to install heat meters or heat cost “allocators” which are likely to have a continuous effect on people’s energy use – in addition to dwelling-level metering and billing.

Energy efficiency measures do not take care of themselves; their energy-saving potential is almost entirely dependent on the human component acting to realise that potential. High-rise buildings offer a significant opportunity to provide effective energy efficiency advice, especially where there is a condominium arrangement; designated individuals can adopt responsibility for acting as a source of advice on the proper use of installed systems for the other residents. Leaflets and posters can be displayed in the shared areas of the building. With are a large number of households under one roof, with most likely to have known each other for a few years at least, there are obvious economies of scale in energy advice provision. Furthermore, energy advice research has shown friends and neighbours to be amongst the most effective sources of information.

Where people are paying for the amount of energy they use – even provided the installed energy saving measures are used effectively — there is usually a comfort-taking effect. This is an increase in energy consumption which partially compensates for the reduced energy expenditure. It can take a variety of forms, including the increased use as well as the acquisition of additional household appliances. Appliance use across Europe generally is on the rise, and energy efficiency refurbishment has little to no effect on this aspect of energy-use culture. Nevertheless, the intervention itself and the associated required provision of energy advice described above present an opportunity to go beyond information about the installed measures by additionally offering tips on how to save energy when using household appliances.

4.4.2. Stakeholder Communication and Environment

Successful energy efficiency refurbishment depends on stakeholders' support and cooperation. The case studies in section 5 highlight some specific examples where stakeholder attitudes and behaviour can make refurbishment projects easier or more difficult. Mentioned in the legal context in section 4.3.3, consultations with stakeholders – residents in particular – provide the best, and above all a pre-emptive opportunity to identify objections to the refurbishment and potential barriers to achieving the projected energy savings. A major threat to a successful project, mistrust between stakeholders – for instance between those initiating or carrying out the project and those who stand to gain from it – is usually the result of information withheld or information not communicated. A lack of trust or confidence can also prove a significant barrier to building the working partnerships necessary to carry out refurbishments, such as is possible in public-private partnerships or relationships between regulators and the regulated. Communication problems are not necessarily at the root, nor the only cause of mistrust and other difficulties; 'not my problem' attitudes on the part of residents accustomed to the authorities or the landlord taking care of things and conflicting objectives between different stakeholder groups pose equally significant threats to the successful completion of projects and achievement of objectives. Sometimes it is not possible to resolve a conflict between stakeholders, no matter how carefully relationships are managed; it then becomes important at the very least to 'agree to disagree', so as not to exacerbate the situation.

Sometimes communication issues can be resolved through intermediary stakeholders that enjoy greater trust with residents. The best examples relate to independent sources of information, such as a local clinic rather than a local authority advising residents to install insulation to keep warm in winter because the local authority is perceived as corrupt, or a university rather than an equipment installer arguing in favour of a certain type of heating control because the installer's reputation may have been damaged by an unskilled or poorly skilled workforce. Connected to institutional capacity (see section 4.1.1), independent bodies and independent quality control have the capability to allay fears and remove barriers to investment in energy efficiency, but the examples cited are arbitrary. Residents may as well trust a local authority more than a clinic if the latter is perceived as administratively incompetent. The important thing is to build on good existing relationships and to enable independent arbitration where relationships are weak.

Barriers to successful stakeholder involvement in refurbishment may lie deeper than trust. Residents may not want to live in high-rise buildings; they may through personal experience associate high-rise estates with depression, suicide, prostitution and drugs, and would rather move out at the earliest opportunity[57]. Depending on the standpoint of the investor – for instance whether the investor is private or public – this perception could deter or encourage refurbishment. Energy efficiency alone can only contribute a small part of what would be necessary to change such perceptions. In the context of wider sustainable refurbishment of high-rise residential buildings however, which can deal directly with problems such as those listed above through community development and regeneration, energy efficiency plays an integral part in changing negative perceptions by providing additional direct and indirect benefits to residents and other stakeholders.

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[57] Land (2002)

5. CASE STUDIES

The case studies have been selected to cover a variety of climate and socio-economic regions to highlight the practical potential, opportunities and barriers of energy efficient high-rise refurbishment. The full length, illustrated case study reports are available separately.

5.1. **Radomir, Bulgaria – How Accession can breed Success**

Built around 1980, “Block One” is one of six high-rise buildings refurbished as part of the PHARE-funded pilot project in Radomir. Commenced in June 1995 and taking 41 months the project included insulation of the external walls, roof and basement ceiling, stopping of gaps in building joints, windows and doors, and overhaul of the heating system. The Bulgarian Committee of Energy was the contracting authority and coordinator of this project while a consortium including the Exergia SA (Greece), ENERGOPROJEKT (Bulgaria) and ICEU (Germany) carried out the refurbishment. Residents were consulted during the design stages of the project and then again after the works had been executed, by way of a mailed questionnaire. They were able to comment on changes in the thermal comfort of their homes, and heating and hot water expenditure. The municipality of Radomir was also consulted and undertook further dissemination of the project. The payback period combining all energy efficient measures on the building’s envelope and installation of local heating system has been estimated at a very short nine years.

5.2. **Budapest, Hungary - Local Government puts ‘refresh’ into Refurbishment**

“Csombor Utca” is a Hungarian multi-family high-rise building and was built in 1980 with insulated pre-fabricated concrete panels. The refurbishment project was initiated and co-funded by the Kobanya local government with additional funding from the European Community and the residents. The Kobanya government adopted a very hands-on role, meeting residents’ requests for involvement and ensuring that their financial burden was tolerable. While some delays were experienced, this commitment led to significant energy savings in a building whose major stakeholders lauded the project as innovative and successful.

5.3. **Riga, Latvia – Innovative Financing takes Pilot to Programme**

“Ozolciema iela 46/3” in Riga is a typical circa 1990 CEE high-rise comprising 9 storeys and built of lightweight single layer prefabricated concrete panels. In 1999 the Senate for Urban Development in Berlin and The Latvian Ministry for Environment and Urban Development in Riga agreed to refurbish the building as an energy efficiency pilot for high-rise buildings. Managed by IWO (Initiative Wohnungswirtschaft Osteuropa – Housing Initiative for Eastern Europe), this pilot led to an ongoing refurbishment programme across Latvia. Improvements to the building included insulation to the façade, roof and basement ceiling. New windows were added and the heating system was completely overhauled, including new pipe work and the installation of regulating and monitoring equipment. These improvements were achieved without having to decant the building's residents. Completed in 2001 and as a result of the improvements, residents' heating bills were approximately halved while comfort improved markedly. Approximately 53% or 50,000m^3 of gas per year is being saved. Due to these results, the pilot was to become the springboard launching a Latvian programme demonstrating the financial feasibility of energy efficient high-rise refurbishment (phase two, 2003-2005) and finally leading to a self-supporting Latvian housing revitalisation programme (phase three, 2005+).

5.4. Lisbon, Portugal – Taking the Heat out of High-rise

"Ceuta Norte" was a demonstration project partly funded by the EC's SUNH programme and built in the city of Lisbon, Portugal. It is a new-build that was selected as a case study because of difficulties finding a high-rise refurbishment in Europe illustrating the possibilities for reducing cooling demand. Sixty-two apartments were newly constructed integrating various solar shading devices, insulation, low-e double-glazing and thermo-mechanical ventilation. The combination of measures enabled significant reductions in solar gain through windows, significant reductions in heat loss and gain through walls, roof and windows, and improved ventilation. Energy savings for heating and lighting, compared to a 'standard' building of this type, were estimated at 50 kWh/m^2 year.

5.5. London, United Kingdom – Raising the Standard in Resident Consultation

Glastonbury House is a residential high-rise managed by CityWest Homes, an ALMO (or Arms-Length Management Organisation) responsible for administering and funding all of Westminster City Council's 22,000 homes in London. This arrangement allowed CityWest to promote the tower's needed refurbishment as an 'intelligent and green' pilot. Early and robust resident and wider community consultation enabled residents a great deal of discretion in choosing colours, layout and materials used in their refurbished apartments, and saw the integration of community-usable health facilities. Innovative virtual reality technologies enabled residents to take a virtual tour of their individual apartment and change its various features such as tile colours or light fittings. Decanting is to be handled by availing newly refurbished 'hotel' apartments in the building to residents while works on their own properties are completed. Emission-reducing improvements include the glazing of balconies, the overhaul of heating including connection to District CHP, and erecting a wind turbine to the top of the building.

5.6. **St Petersburg, Russia – Self-funding High-rise Refurbishment?**

Torzhkovskaya 16 is a 1950's five-storey residential high-rise block built in the equivalent of a cold climate EU region. The costs of refurbishing the building were prima facie, largely offset by the value added by constructing an attic storey of nine apartments. Through a PPP involving the Danish government, local municipality, the non-profit Foundation for the Construction of Attics and several sponsoring companies, the refurbishment was able to achieve outstanding reductions in energy consumption (67%). This was achieved by insulating the entire building envelope, stopping all gaps in the windows, and overhauling the district-connected heating system so that residents could monitor and regulate individual radiators.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This project has attempted to establish and assess the current situation of and potential for energy efficiency in the refurbishment of high-rise residential buildings in Europe. This has been done against the backdrop of the European Housing Ministers' official recognition of the residential high-rise stock as a priority for sustainable refurbishment – of which energy efficiency improvement is a key part. In this regard, the project has found – through both high-rise stock-wide assessments and the modelling of individual base buildings – that there is a vast, cost-effective and untapped energy saving and CO_2 mitigation potential.

In order to find and develop a way forward for the integration of energy efficiency into the refurbishment of high-rise buildings, the project has drawn together and assessed a wide range of opportunities and barriers to better inform the recommendations for policy as well as further research. The six separately produced case studies of high-rise refurbishment illustrate some of the realities of the energy saving and CO_2 mitigation potential, wider benefits, and the opportunities and barriers faced.

The recommendations that follow are based on a high level of confidence in this project's findings. While the research carried out has stayed with the European Housing Ministers' definition of high-rise residential buildings (i.e. as having more than four storeys) in order to be 'in line' with other research and with real policy development and momentum, it is important to note that all or most of the recommendations are likely to be just as applicable to large multi-family buildings with four storeys or less.

6.2. Recommendations

6.2.1. For policy

In recognition of the cost-effective and very substantial CO_2 emissions reductions that can be achieved, especially in EU10 and AS3 countries but also in EU15 countries with the existing pattern of energy prices, we propose that policy makers:

- Recognise the inherent market failures and barriers to energy efficiency refurbishment that apply in the building sector as a whole, but most acutely in shared residences, and devise and implement policies to remedy them.

- Incorporate energy efficiency improvement as a legal requirement whenever refurbishment is undertaken in high-rise buildings to maximise cost-effectiveness of investment.
- Facilitate and support the creation of new European funds to accelerate sustainable, energy efficient refurbishment – especially for EU10 and AS3 countries where it is most needed, and because no structural funds for housing or energy demand management exist as yet.
- Consider adoption of Danish-style requirements for condominium dwellers to contribute a small monthly payment to a refurbishment fund.
- Consider introduction of fiscal incentives for refurbishment such as tax-deductions for refurbishments that improve the overall energy performance of the building or lower rates of tax on the rental income of landlords that improve the energy performance of their rental stock.
- In the case where high-rise residences are owned by local authorities, consider developing specific additional funds and obligations for energy-efficient refurbishment.
- Consider implementation of general energy efficiency delivery mechanisms that could be used, amongst other purposes, to fund energy-efficient refurbishment activities (potential examples include: a broadened version of the UK Energy Efficiency Commitment scheme and the Italian or French White certificate schemes).
- Prepare for energy market liberalisation, in particular in EU10 and AS3 countries, and ensure that individual metering and billing replaces the existing energy consumption infrastructure.
- Close gaps in building or estate level condominium legislation/collective decision-making rules to facilitate refurbishment.
- Link all actions to implementation of the Energy Performance of Buildings and Energy End-use Efficiency and Energy Services Directives.

Taking the opportunities identified in this study will require work to synchronise the objectives of various government departments and other authorities involved in the delivery of sustainable housing and energy. To this end there is a need to employ consistent methodologies across government to quantify the wider benefits of energy efficiency improvement and to commission further research to identify the most innovative forms of financing.

6.2.2. Priorities for further research

- Need to research and explore potential synergies between the Energy Performance of Buildings and the Energy End-use Efficiency and Energy Services Directives, especially with respect to high-rise and large multi-family buildings.
- To survey the extent to which the high-rise and large multi-family stock is over- or under-heated and where – in order to quantify the amount of energy 'take-back' and inform the development of proportionate energy advice provision.

- Need for collection and analysis of data on potential for and investment in reducing cooling demand in high-rise residential and large multi-family buildings to quantify cost-effectiveness and develop cooling reduction/avoidance strategies.
- Similarly, need for collection and analysis of data on potential for and investment in high-rise and large multi-family building-integrated renewable energy technologies, to quantify cost-effectiveness and complement energy demand reduction and energy efficiency improvement.
- Special need for modelling and consumer surveys of impact of new types of financial incentive for high-rise and large multi-family building refurbishment, such as financial incentives linked to the level of certification achieved under the Energy Performance of Buildings Directive.

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ANNEX I – DEFINITION OF SUSTAINABLE HOUSING

As defined at the 3rd Housing Ministers Conference on Sustainable Housing in Genval, 2002, and from paragraph 4 of its final communiqué (quoted in PRC Bouwcentrum International 2005).

A Construction Perspective

This aspect primarily refers to the quality of the construction and involves two main elements:

- Life-span, closely linked to the quality of the building materials used their utilisation and maintenance, and the ability of the managers to implement a continuous maintenance.
- Adaptability, which needs to be considered on two levels: the successive occupiers or occupational users within the same accommodation and the changing needs of the same occupant in the same accommodation.

A Social and Economic Perspective

This aspect refers both to the viability of accommodation for the occupier, whether tenant or owner, and to the importance of housing for social cohesion which notably includes:

- Affordability, based on the actual financial means of the occupiers in order to enable them to control the direct costs of the accommodation without having to neglect other essential needs (nutrition, health, education, culture, etc.).
- Access to housing, which means, for instance, tackling the various causes of homelessness through a variety of policies.
- Accessibility for the disabled and aged.
- Indirect costs such as commuting and travel costs linked to the location of the housing; impacts of housing, more specifically in terms of indoor pollution, and the wider residential environment on the physical and mental health of the occupiers.
- Psychological and social function of the housing and the residential environment: changing it from a “place to live” to “home”, while at the same time encouraging the development and maintenance of social networks and various types of social solidarity.
- Improving the viability of the housing areas and especially underprivileged urban areas, including the socio-economic fabric, via urban renewal programmes.
- Supporting mixed housing through policies that fight segregation and promote a balanced distribution of all forms of tenure and all types of buildings.

An Eco-efficiency Perspective

Aiming for an improvement in the quality of life and control of the quality and the use of resources, based on the following elements:

- Rational and efficient use of natural non-renewable resources, both in the construction and the use of housing; these resources can be grouped under four main headings.
- Land use: the use of land, a limited key resource and whose efficient management should be optimised in order to limit the use of land across a range of human activities including housing, together with an assessment of the total ecological impact of housing versus other uses, e.g. agriculture.
- Energy: level of energy consumption (direct and indirect) and type of energy used.
- Construction materials and whole buildings: their renewable character and notably their “embodied energy” as well as the ecological costs of disposal.
- Water: level of consumption and the quality of the consumed water.
- Ways to produce housing as ecological as possible.
- Achieving increases in comfort with less additional resources, particularly by the use of technical innovations.

ANNEX II – METHODOLOGY DETAILS AND ASSUMPTIONS

Data Sources

Data for the calculation of cost-effectiveness of energy efficiency investment in high-rise buildings have been drawn from a variety of sources:

- Construction and thermal properties of high-rise buildings, both before and after energy efficiency improvement, in different countries and regions, have been sourced from existing studies and projects, most pertinently PRC Bouwcentrum International (2005), Petersdorff *et al* (2004b), the OPET Building network (ECB *et al*, 2004), and, crucially, expert opinions from EuroACE member companies. Where possible, data from national housing surveys were also used.
- Household energy prices for the different countries and predominant fuels used for heating in high-rise buildings were sourced from Eurostat (2004).
- Data on countries' CO_2 emissions, both total and from the residential sector were sourced from the IEA (2001a).
- Data on energy saving potential in the high-rise stock were taken from PRC Bouwcentrum International's (2005) survey of European housing ministries for VROM.

Methodology

The following simple formula, based on the principles of the European Standard EN 832, and applied also in Petersdorff *et al* (2004b), was used to calculate the energy savings arising from the implementation of the quantitatively assessed energy efficiency measures.

$$\Delta E = HDH * \Delta U * \frac{1}{\eta}$$

Where:	ΔE	[kWh/m^{2}a]	energy savings (related to the surface area of constructional element)
	HDH	[kKh/a]	heating degree hours
	ΔU	[W/m^{2}K]	difference between U-values before and after retrofit
	η	[-]	efficiency of heat generation and distribution

Using this approach, with all results normalised to per m^2 of heated floor space, energy saved, annualised investment cost, payback time, net present value in Euros per kWh of energy saved and the net present value per tonne of CO_2 mitigated, could be calculated.

Heading Degree Days of the 28 Countries[58]

Country	*Heating degree days*
Austria	4298
Belgium	3105
Bulgaria	3378
Cyprus	1275
Czech Republic	3234
Denmark	3697
Estonia	4502
Finland	5215
France	2412
Germany	1664
Greece	3911
Hungary	3258
Ireland	3181
Italy	2091
Latvia	4490
Lithuania	4344
Luxembourg	3658
Malta	1530
Netherlands	3221
Poland	3851
Portugal	1855
Romania	3374
Slovakia	3305
Slovenia	3382
Spain	2137
Sweden	5004
Turkey	2675
United Kingdom	3076

- The starting energy price for each country was based on an average of the last three years (2002-2004). As a lower boundary, energy prices were assumed to increase by 1.5% a year in *real* terms – hence, annuity factors are not applied to energy cost savings. On this basis, the average energy price for the years 2004-2034 was used to carry out the cost-effectiveness calculations.

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[58] data from European Climate Assessment & Dataset project; http://eca.knmi.nl, last accessed 1.11.04, adapted to a 19°C base temperature

- A standard heating system efficiency of 75% has been assumed (100% for electricity). New heating systems, where implemented, have been assumed to be condensing systems with an efficiency of 97%.
- All base building region values are weighted averages of the country values in the region.

ANNEX III – DATA UNDERLYING FIGURES II TO V

In these tables, the data marked in bold indicate the best results for each indicator.

Energy Savings, Investment Costs and Cost of Conserved Energy

	Energy saved [kWh/m^{2}a]		Annual investment cost [€/m^{2}a]	Cost of conserved energy [€cent/kWh]	Simple payback [a]
EU15/warm climate (A)	132.6	71.0%	2.61	2.0	**2.7**
EU10/warm climate (B)	123.1	71.7%	**2.08**	1.7	6.1
AS3/warm climate (C)	115.9	71.1%	1.85	1.6	14.5
EU15/moderate climate (D)	178.1	74.9%	3.94	2.2	**4.5**
EU10/moderate climate (E)	135.5	74.7%	2.10	**1.5**	8.6
AS3/moderate climate (F)	133.4	73.1%	**1.77**	**1.3**	11.3
EU15/cold climate (G)	171.6	75.9%	4.07	2.4	**5.7**
EU10/cold climate (H)	140.2	69.6%	**1.95**	**1.4**	10.5

Energy Savings, Costs of Energy and of CO_2 Mitigation

	Energy saved [kWh/m^{2}a]		Cost of supplied energy [€cent/kWh]	Cost of conserved energy [€cent/kWh]	Net cost of conserved energy [€cent/kWh]	Cost of CO_2 mitigation [€/tCO_2]	Net cost of CO_2 mitigation [€/tCO_2]
EU15/warm (A)	132.6	71.0%	**12.4**	2.0	**-10.4**	93	**-497**
EU10/warm (B)	123.1	71.7%	4.8	1.7	-3.1	84	-152
AS3/warm (C)	115.9	71.1%	1.9	1.6	-0.3	79	-13
EU15/mod. (D)	178.1	74.9%	**8.8**	2.2	**-6.1**	97	**-268**
EU10/mod. (E)	135.5	74.7%	3.0	**1.5**	-1.5	**68**	-66
AS3/mod. (F)	133.4	73.1%	2.0	**1.3**	-0.7	**58**	-29
EU15/cold (G)	171.6	75.9%	**7.1**	2.4	**-4.8**	97	**-195**
EU10/cold (H)	140.2	69.6%	2.3	**1.4**	-0.9	**57**	-36