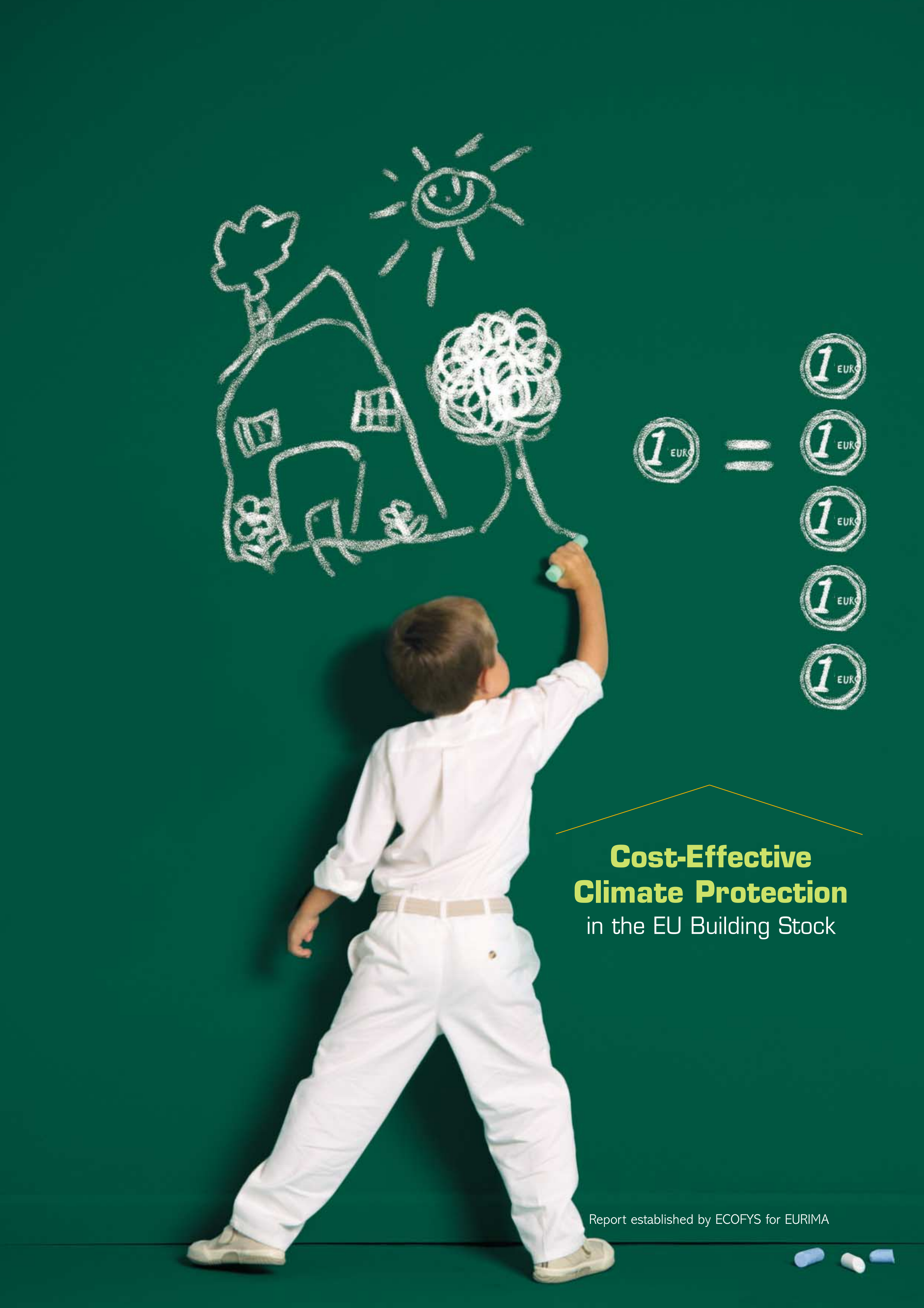

Cost-Effective Climate Protection
in the EU Building Stock

Report established by ECOFYS for EURIMA

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EXECUTIVE SUMMARY

The large gap between EU targets under the Kyoto protocol and current greenhouse gas emission levels in Europe, together with the necessities of long-term climate protection, requires a substantial further reduction in emissions. These reductions should be achieved without loss of competitiveness or jobs. Instead it is highly desirable that clear additional benefits are realised hand in hand with greenhouse gas emission reductions such as the improvement of urban air quality, increased security of the energy supply and the creation of sustainable new jobs.

Ecofys' previous study for EURIMA "Mitigation of CO_2 Emissions from the Building Stock" [Ecofys 2004] identified a significant potential for greenhouse gas emission reductions in the building sector. This is partly covered by the European Directive on Energy Performance of Buildings (EPBD) leading to CO_2 emissions-savings of 34 Mt/a by the year 2010. However, by extending the scope of the EPBD to smaller buildings, this potential could be increased by a factor of 2. Since economics are of decisive importance in achieving these potentials, this new study examines the economics of suitable measures for the building sector.

In evaluating possible measures to reduce the heat energy consumption, which could become standard by the time the EPB Directive is implemented into national legislation, this study finds that most measures can be carried out in a cost-effective way. Very significant cost-saving potentials are found to exist, particularly in warm and moderate climatic zones. However, even in colder climates there is still justification for the application of energy reduction measures to the relatively small numbers of houses which still have a rather poor energy-efficiency standard.

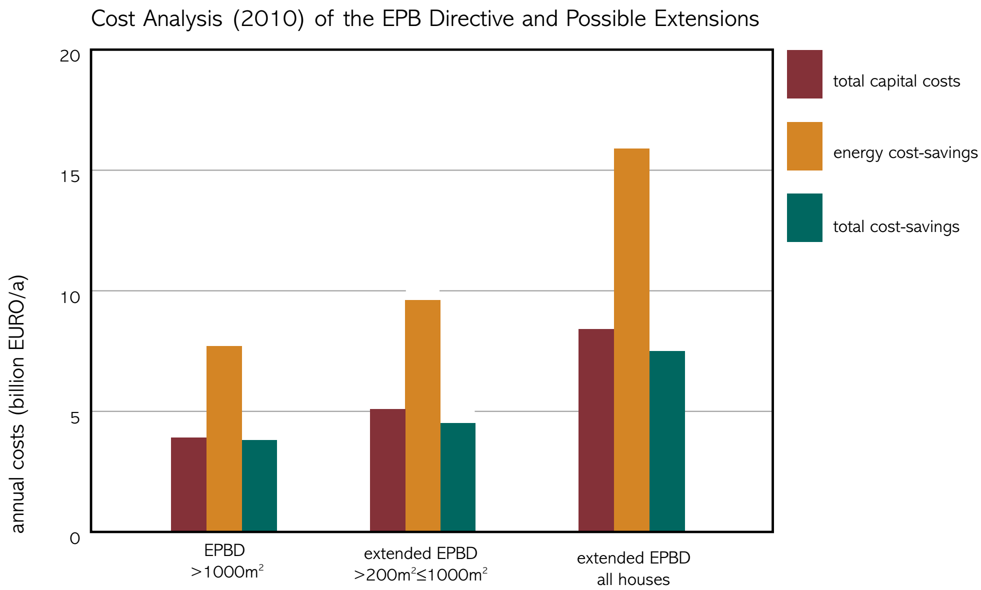
In economical terms the biggest opportunity is found to be the coupling of energy-efficiency measures with general maintenance and retrofit measures. Such an opportunity typically arises within the normal retrofit cycle only when buildings reach an age of about 30-50 years. Therefore efforts should be directed at utilizing the chance of combining regular retrofits with energy-saving measures.

Due to the cost-effectiveness of most insulation measures the study confirms that the principle of "Trias Energetica" should be applied to energy use. This states that the first requirement is that demand be reduced and unnecessary energy losses must be avoided. After that it is necessary to generate the remaining demand from renewable resources and to use fossil fuels as efficiently as possible. Applying the principle to the building stock means that a good insulation standard is a pre-requisite for sustainable buildings.

An analysis for the EU reveals that fairly significant additional investments will be required: It is estimated that full implementation of the EPB Directive for new and large buildings in all countries will lead to an annual investment of nearly 10 billion EURO beginning in 2006. Extending the scope of the EPB Directive to all buildings, the annual investments would increase to about 25 billion EURO. However, in the context of total EU construction activities energy-efficiency measures represent a minor share at only 1-3% of the total turnover. In economic terms these investments would result in net annual cost reductions for national economies, thus making such measures profitable.

Converting investments into annual capital expenditure and relating them to annual cost-savings displays the profitability of applying energy-saving measures at the EU level (see Figure 1). Implementation of the EPB Directive would result in yearly cost reductions amounting to around 4 billion EURO in the year 2010 rising to 8 billion EURO if the scope of the Directive were to be extended to all house types.

Figure 1: Cost Analysis of effects of the EPB Directive and possible extensions in 2010



	EPBD >1000m²	extended EPBD >200m²≤1000m²	EPBD all houses
total capital costs	3.9	5.1	8.4
energy cost-savings	7.7	9.6	15.9
total cost-savings	3.8	4.5	7.5

In comparison to some other instruments of national and EU climate policy the measures proposed in this study for application in the building sector are highly competitive. They do not impede the economic competitiveness of internationally operating businesses and there are no effects indicated which would require the relocation of production facilities. Also, the measures help to improve air quality in urban areas – another important environmental priority within the EU. Finally, positive effects on employment are to be anticipated. Based on this analysis, it can be concluded that moderate positive employment effects (in the range of around 10,000 to 100,000 jobs across Europe) would result from the implementation of the discussed energy-saving proposals.

Despite the cost-effectiveness of the measures discussed in the scenarios, some of them will not be widely implemented autonomously for the following main reasons:

> in rented accommodation retrofit measures increase the investment cost for the owner and deliver a benefit (in terms of increased comfort and lower energy bills) for the tenant making such investments unattractive for owners unless rents can be increased;

> in investment decisions, the availability of capital may overrule the more long-term economic considerations of the investor, especially for small privately-owned houses.

In summary, the utilisation of energy-saving potentials in the building sector is highly desirable on societal and individual levels. This may require significant efforts by owners, architects and planners, but it can be supported by incentives at the political level. Establishing revolving funds for refurbishment projects, providing incentives through reduced interest rates on loans or lowering the Value Added Tax on certain energy-saving products may accelerate the implementation of energy-efficiency measures.

CONTENT

1] INTRODUCTION

1.1 EU CLIMATE POLICY

Under the Kyoto Protocol agreed in 1997 at the third meeting of the parties of the United Nations Framework Convention on Climate Change (UNFCCC) the EU committed itself to reducing its greenhouse gas emissions by 8% compared to 1990 levels in the 2008-2012 period. Even more ambitious reduction goals were set in the Sixth Environmental Action Programme (6-EAP) adopted in 2002: the stabilization of the atmospheric concentration of greenhouse gases at levels that will not cause dangerous variations of the earth's climate was set as the ultimate objective. In order to achieve this, the 6-EAP states that a long-term reduction of worldwide greenhouse gas emissions to approximately 70% below 1990 levels is needed. Given this long-term objective, a global reduction of the order of 20–40% from 1990 to 2020 will need to be pursued by the EU.

In order to achieve these goals, the EU has developed several instruments aimed at greenhouse gas emission reductions. In January 2005 an EU-wide emissions trading system (EU-ETS) is to start. This system involves CO_2 emissions from installations in energy intensive industries. The first trading phase is from 2005-2007, the second will be in line with the Kyoto commitment period, from 2008-12. Since the Kyoto Protocol offers two project-based mechanisms, the Clean Development Mechanism (CDM) and Joint Implementation (JI), to increase flexibility for countries in reaching their reduction targets, these mechanisms have been linked to the EU-ETS. Reduction certificates from CDM or JI projects matching specific criteria can now be sold into the EU-ETS and used for compliance by operators of installations.

Currently a gap of roughly 190 Mt CO_2 eq. per year remains between the current emission levels of the EU-15 and the target under the Kyoto-Protocol for the year 2010 [EEA 02]. The energy and industrial sector will probably contribute only a fraction of this reduction via the newly established EU emissions trading scheme and connected projects under the flexible mechanisms. In addition, the traffic sector is likely to continue on a growth path leading to a widening of the gap. Thus, the EU building sector is now under scrutiny to contribute to the EU climate targets beyond what will be achieved by means of national energy-efficiency legislation and the new Energy Performance of Buildings Directive (EPBD).

1.2 THE EUROPEAN BUILDING STOCK

Despite substantial savings achieved since the 1970's energy crisis began a considerable potential for energy-savings remains in the building sector [Caleb 98, Caleb 99, IWU 94], since it is responsible for about 40% of Europe's total final energy consumption. Two studies [Ecofys 2002, Ecofys 2004] carried out for EURIMA in 2002 and 2004 explored the reduction potential of the EU-15 building stock -on the one hand through insulation techniques, on the other hand through the various measures within the boundaries set within the EU Directive on the Energy Performance of Buildings.

The European Directive on Energy Performance of Buildings (EPBD), which came into force 16 December 2002, will be implemented by Member States by 4 January 2006. Four main elements define the requirements that need to be integrated into national legislation:

> Establishment of a methodology for integrated calculation of the overall energy performance of buildings;

> Definition of minimum energy-efficiency requirements per member state based on this methodology. In addition to the aim of improving the overall energy-efficiency of new buildings, large existing buildings will become a target for improvement as soon as they undergo significant renovation;

- Energy-efficiency certification of new and existing buildings;
- Regular inspection of heating and air conditioning systems.

The above-mentioned study "Mitigation of CO_2 Emissions from the Building Stock" [Ecofys 2004] demonstrates that the European Directive on Energy Performance of Buildings will have a significant impact on the heating related CO_2 emissions of the European building stock. Therefore the influence of insulation on the energy demand for cooling was not in the scope of the scenarios.

Compared to a business as usual (BAU) scenario under which common practice for energy-efficiency is applied to new buildings and retrofit measures, the current EPB Directive leads to CO_2 emission reductions of 34 Mt/a in the year 2010. However, since single-family houses represent the largest share of buildings (45%), CO_2 emissions could be reduced even more significantly if the scope of the Directive were extended to include smaller buildings. Extension of the scope of the Directive to all buildings would create an additional emission savings potential of 36 Mt/a.

1.3 COST-EFFECTIVENESS OF ENERGY-SAVING MEASURES IN THE EUROPEAN BUILDING STOCK

With good reason decisions on policies and measures at the EU level depend not only on CO_2-reduction potential but also on the cost-effectiveness of these measures. The criterion which is commonly applied is the annualised mitigation cost in EURO per ton of CO_2 avoided. Within this context the economic benefits of thermal insulation must be considered in the implementation of energy-saving measures in the building stock. In doing so, not only investment costs need to be taken into account but also the cost-savings achieved during the lifetime of energy reduction measures. It goes without saying that saving energy not only helps to mitigate climate change and reduce energy costs but also improves air quality and reduces dependence on energy imports leading to improved security of energy supply.

1.4 OBJECTIVES OF THIS STUDY

In addition to the above mentioned Ecofys report [Ecofys 2004] this study quantifies the required investments in energy-efficiency and analyses their cost-effectiveness which must be demonstrated in order to mobilise the total energy-saving potential in the EU-15 building stock. However, it is not only aggregated results for the whole of Europe which are investigated. The further objective of this study is to assess potential individual reduction measures over their life-cycle, including insulation, as well as suitable packages composed of individual measures. Therefore the report is divided into two parts:

- In the first part individual measures and energy retrofit packages, which could become standard when the EU EPB Directive is implemented into national legislation are analysed. The measures and packages are investigated for three climatic zones;
- In the second part the economic impact of applying these packages to the existing building stock of Europe is analysed under different scenarios of the implementation of the Directive and its possible extensions.

The report draws conclusions and makes policy recommendations for initiating the required investments at the EU-15 level.

2] THE ECONOMIC ASSESSMENT METHODOLOGY

This chapter describes the methodology used to analyse the cost-effectiveness of individual measures and feasible packages of measures to reduce the heating energy consumption in buildings.

2.1 THE EU-15 BUILDING STOCK

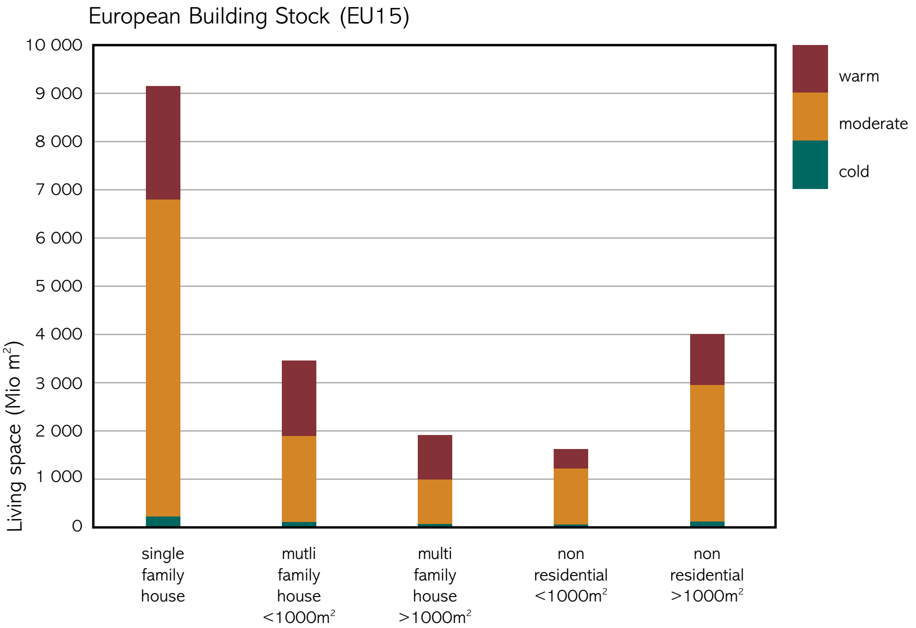
To take the different climate conditions and cost parameters into account, three climatic regions have been distinguished: cold, moderate and warm. Table 1 assigns the building stock of Member States to these three climatic zones.

Table 1: *Attribution of Member States to climatic regions*

cold	moderate		warm
Finland	Austria	Germany	Greece
Sweden	Belgium	Ireland	Italy
	Denmark	Luxemburg	Portugal
	France	The Netherlands	Spain
		United Kingdom	

Figure 2 shows the distribution of living areas of the current building stock for different climate zones and house types.

Figure 2: *Living areas of climate zones and house-types (EU-15 building stock 2002)*



A detailed overview of the EU-15 building stock and its age distribution is annexed (see Table 40).

2.2 COSTS DURING THE LIFE-CYCLE

For an economic assessment of CO_2-mitigation measures it is not only investments which are relevant but also the fuel, maintenance and operational cost-savings that are realised. The chosen methodology allows the different costs over the whole life-cycle of energy-saving measures to be compared.
The main elements of these life-cycle costs are capital costs and annual running costs which sum up the operational or energy costs and the maintenance costs.

2.2.1 Capital Costs

Capital costs result from the investment in energy-saving measures. Two different investment costs for energy-saving measures are distinguished:

> **The total investment costs**

The total investment costs for insulation and energy-efficiency measures in a retrofit which is implemented as a "stand alone" building project include material, labour, applicable taxes as well as overheads and profits. Here, the energy-efficiency measures are the sole reason for expenditure. The estimated investment costs are included for each measure and climatic zone in the description of the measure itself. They are based on existing literature [Schmitz 02, Feist 98, Schöberl 03; IWU 94] and interviews with building experts throughout Europe, which were carried out as part of the project. These costs are reported in equivalent value of 2002 EURO. In general there is a decline visible from higher prices in Northern Europe to lower prices in Southern Europe. One reason for this is the parallel decrease in labour costs from Northern to Southern Europe. Also, in general, hardware costs decrease from Northern to Southern Europe due to specific market conditions.

> **Energy related investment costs (energy measures coupled to general retrofit)**

Energy-saving measures may also be undertaken as part of the conventional retrofit cycle of buildings. Here, they can be combined with other necessary refurbishments and replacements. When energy-saving measures are coupled with renovation the energy-related investment costs can be reduced compared to the "stand alone" case. For example, the installation of roof insulation can be combined cost-effectively with the renewal of a leaky flat roof. Hence, this study compares "stand alone" energy-related investment costs with energy-efficiency measures applied within the renovation cycle. In other words: **the energy related investments are the total investment costs minus the investment costs for renovation without energy improvements (pre-existing energy-efficiency measures kept in place).**

2.2.2 Operation and Maintenance Costs

The annual operation and maintenance costs can be classified into energy costs and other operational and maintenance costs.

> **Energy costs and operation costs**

Energy costs are by far the largest component of annual operational and maintenance costs for the investigated measures. The study has calculated energy costs based on energy rates and the assumed respective increase rates displayed in Table 2. Average values for the different climatic zones are taken into account. Due to the variation of energy prices in different countries results may differ for specific national circumstances.

***Table 2:** Energy rates for different end energy carriers [deduced from EC 03; Eurotat 02; Enquete 02]*

	Energy tariff 2002	Annual rate of increase	Average value 2002-2032
	cent/kWh		cent/kWh
Gas	4.03	1.50%	5.16
Oil	3.68	1.50%	4.71
Electricity	8.84	1.50%	11.33
District heating	5.00	1.50%	6.41
Wood	3.61	1.50%	4.24

The energy demand for heating of the house types assessed was calculated according to the principles of the European Standard EN 832. Please note that the influence of cooling is not taken into account. The energy-savings of different insulation measures are calculated according to the following equation:

$$\Delta E = HDH * \Delta U * 1/\eta$$

ΔE	[kWh/m²a]	Energy-savings (related to the surface area of the constructional element)
HDH	[kKh/a]	Heating Degree Hours (see Table 3)
ΔU	[W/m²K]	Difference of U-values before and after retrofit
η	[-]	Efficiency of heat generation and distribution

***Table 3:** Heating Degree Hours of different climatic zones [Ecofys 2004, STOA 98]* [1]

Climatic zone	cold	moderate	warm
HDH [kKh/a]	108	72	43
Heating degree days [Kd/a]	4500	3000	1800

> Other Operational and Maintenance Costs

Within the standard retrofit cycle the operational and maintenance costs for insulation is negligible. The maintenance costs for technical equipment such as gas boilers can be seen as constant and are about 1% of the investments [VDI 2067]. However, in the assessment of energy-saving measures results are usually compared to a reference with the same maintenance costs, as long as no fuel switching takes place. Therefore the maintenance costs have no influence of the economic assessment and no non-energy operational and maintenance costs are considered.

[1] One heating degree day [Kd/a] corresponds to 0.024 heating degree hour [kKh/a]

2.3 ASSESSMENT CRITERIA FOR LIFE-CYCLE COSTS

To assess the cost-effectiveness of energy-saving measures in the building stock over the whole life-cycle, different assessment criteria are used in this report.

2.3.1 Amortisation

The amortisation period is a transparent criterion for the assessment of the profitability of energy-saving measures. It indicates the time span after which the investments are recovered from the energy cost-savings, expressed on annual basis. It has as a disadvantage that the costs of financing are not taken into account.

2.3.2 Total Equivalent Annual Costs

To account for the costs of financing and compare alternative measures with different life-spans, the total equivalent annual costs are commonly used. The total equivalent annual costs are calculated as the sum of annual operational and maintenance costs, plus annualized capital costs.
Therefore the investments are converted into constant annual capital costs. The investment costs are multiplied by the equivalent annual cost factor or annuity factor, which is based on the lifetime of the measure and an interest rate:

$$a=\frac{(1+i)^n * i}{(1+i)^n-1}$$

a ➡ Annuity factor
i ➡ Interest rate
n ➡ Service Lifetime

Table 4 lists the values chosen for the cost assessment. They are consistent with other EU studies which have evaluated the cost-effectiveness of various climate change mitigation options such as EU DG Environment's "Economic Evaluation of Sectoral Greenhouse Gas Emission Reduction Objectives" [Ecofys 2001]. It is however important to note that these default societal interest rates can differ significantly from capital costs or expected returns on investment for companies or individuals, i.e. the cost optimum for society is often different from an investor's optimum. Public policy however usually attempts to minimise costs to society.
Additionally it is important to note that the values used for the economic lifetime are derived from other studies [VDI 2067, Ecofys 2001, IWU 94]. The actual technical lifetime of the products and its technical applications may exceed the economic lifetime.

Table 4: *Assumptions for calculation of annual capital costs [Ecofys 2001, VDI 2067]*

Interest rate	4%
Service lifetime insulation	30 yrs
Annuity factor insulation	0.0578
Service Lifetime technical equipment	20 yrs
Annuity factor technical equipment	0.0736

2.4 EMISSION MITIGATION COSTS

The EU climate policy aims to avoid future economic damages and risks by reducing greenhouse emissions at minimum costs to society. Most policies and measures to mitigate climate change are expected to lead to some additional cost for end-consumers, companies and governments.

For decisions on policies and measures at the EU level the mitigation costs expressed as annualised EURO per ton of CO_2 avoided are used as the economic criterion. Mitigation costs refer to the last unit and thus most expensive unit to achieve the agreed target.

Table 5 presents an overview of indicative marginal mitigation costs. These costs are not taken into consideration in the economic assessment of the investigated measures but are meant for benchmarking the mitigation costs of the calculated measures. (see chapter 5.2)

Table 5: *Estimates of EU and national marginal mitigation costs [Friedrich 01]*

Source	Assumptions	Marginal mitigation costs
Blok, Jager et all. (2001)	Calculated for the EU-15 to achieve its Kyoto target domestically using all six greenhouse gases and sectors	20€$_{1999}$/tonne CO_2e[1]
Criqui and Viguir (2000)	Calculated for the European Union (EU15) to achieve its Kyoto target provided full flexibility is assumed and all sectors are included	37US$/tonne CO_2e
Capros and Manzos (2000)	Calculated for achieving the EU Kyoto target allowing free trade of emission certificates globally	19€$_{1999}$/tonne CO_2
Fahl (1999)	Calculated for Germany to achieve its Kyoto target	19€/tonne CO_2e
Maibach et al. (2000)	Calculated for a 50% reduction of CO_2 for 2030 compared to 1990 values	135€$_{2000}$/tonne CO_2

It is widely accepted within the EU and its Member States that 20€$_{2000}$/tCO_2e represents an indicative limit of acceptable mitigation costs in the near term – considering the current economic potential for emission reductions balanced against the likely range of future damage and some ancillary benefits.

The report shows the cost-effectiveness of energy-efficiency measures (see section 3 and 4) expressed in mitigation costs and the costs or financial benefits per saved energy unit. By negative values we mean cost-effectiveness. The average cost of energy has been used in the report.

Remark: *Actual energy prices in any particular country should be taken into account to establish the national or local effectiveness of energy-saving measures. A higher or lower national energy price can be considered in the values "cost saved energy" values in the tables "economic assessment of retrofit measures" in the sections 3 and 4 by adjusting the price difference[2]. If the new value is negative the measure is cost-effective.*

[1] The figure must be interpreted as to achieve the target in the most effective manner and includes all Kyoto gases. It was assumed the target could be achieved without global emissions trade but with full flexibility. Full flexibility refers to a European-wide implementation of least-cost measures in different sectors independent of the EU Bubble.

[2] Example: The report uses the average zone price for energy in Table 6 for its calculations. If the local price is 1 cent above this value then the "cost saved energy coupled" for instance in Table 8 should be adjusted from 3.5 to 2.5 cent/kWh in the cold zone.

Figure 3 summarises the calculation principles for the economic assessment of energy-saving measures in the building stock.

Figure 3: *Calculation principles for the economic assessment*

Calculation Principles		
Total investment costs	IC_{total}	(€/m²)
- related to surface area of constructional element for individual measures (chapter 3) - related to heated floor area of investigated house of retrofit packages (chapter 4)		
Energy related investment costs	$IC_{energy\ related}$	(€/m²)
When coupling the energy measures with the regular retrofit cycle, the energy related costs are the total investment costs, minus the investment costs for regular preservation measures without energy improvements (see 2.2.1)		
Annual investment costs	$IC_{annual} = IC_{total/energy\ related} * a$	(€/m²a)
Investment costs converted to annual capital costs; a = annuity (see 2.3.2)		
Saved energy costs	$\Delta EC = \Delta E * EP$	(€/m²a)
ΔE = energy-savings (kWh/m²a) (see 2.2.2); EP = Energy price (€/kWh)		
Total cost-savings	$TC_{annual} = IC_{annual} - \Delta EC$	(€/m²a)
Related to constructional area (individual measures) or heated floor area (packages)		

Decision Criteria		
cost-effectiveness		Policy Decision
Amortisation (Pay Back Time) $A = IC_{total} / \Delta EC$ (a)	**Cost saved Energy** $C_{\Delta E} = TC_{annual} / \Delta EC$ (€/$kWh_{avoided}$)	**Mitigation Costs** $MC = TC_{annual} / \Delta CO_2$ (€/tCO_2e)

3] THE ASSESSED MITIGATION MEASURES

As previously discussed the Ecofys study "Beyond the EU Directive on the Energy Performance of Buildings" [Ecofys 2004] analysed the impact of the EU Directive on the emissions associated with the heating energy consumption of the total EU-15 building stock. The Directive does not give minimum levels for energy performance or thermal insulation. Therefore the impact of the EPB Directive on thermal insulation was assessed by interviews with building authorities and experts throughout Europe. This has resulted in forecasts for thermal insulation levels in the three climatic zones by the time the Directive is implemented in national legislation. In the following these values will be referred to as the "**expert forecast for the EPB-standard**".

As a continuation of the above mentioned report [Ecofys 2004], the present work focuses on the economics of measures identified in the previous report to reduce the heating related CO_2 emissions. Cooling is not a focus of this study. The measures assessed address the building envelope and the energy supply system of buildings:

> Building envelope; reduced transmission loss by:
- Increased insulation of walls
- Increased insulation of roof
- Increased insulation of cellar/groundfloor
- Improved windows with lower U-value

> Renewal of energy supply
For the calculations of the results of retrofit measures on the building envelope (insulation and windows) the following situations are compared:

> Situation before retrofit:
The economic viability of insulation measures is strongly dependant on the energy-efficiency of the building before start of the retrofit measure. In our model calculations, the general energy efficiency status of buildings in Europe built before 1975 and not yet renovated is taken into account.

> Situation after retrofit:
The measures are analyzed for insulation levels according to expert forecasts for the EPB-standard. Additional calculations have been made by varying the possible levels of building insulation in order to determine an economic optimum.

To assess the financial benefit of measures to improve the thermal resistance of the building envelope a uniform average energy price and CO_2 emission factor including all energy carriers (gas, oil, electricity etc.) has been calculated for the respective climatic zones (Table 6). This enables conclusions that are generally valid for the respective climate.

***Table 6:** Characteristics of assumed energy mix in the three climatic zones [Gemis 03, Eurotat 04, Ecofys calculations]*

Climatic zone	Average CO_2 emission factor	Average energy costs (30 years)
	(kg/kWh)	(cent/kWh)
Cold climate	0.245	0.075
Moderate climate	0.229	0.057
Warm climate	0.202	0.051

3.1 INSULATION OF EXTERNAL WALLS

The methods of insulating external walls during the retrofit of energy-efficiency measures to a building depend on the particular structure of the outer walls. Three different types can be distinguished: external insulation, cavity insulation and interior insulation (dry lining).

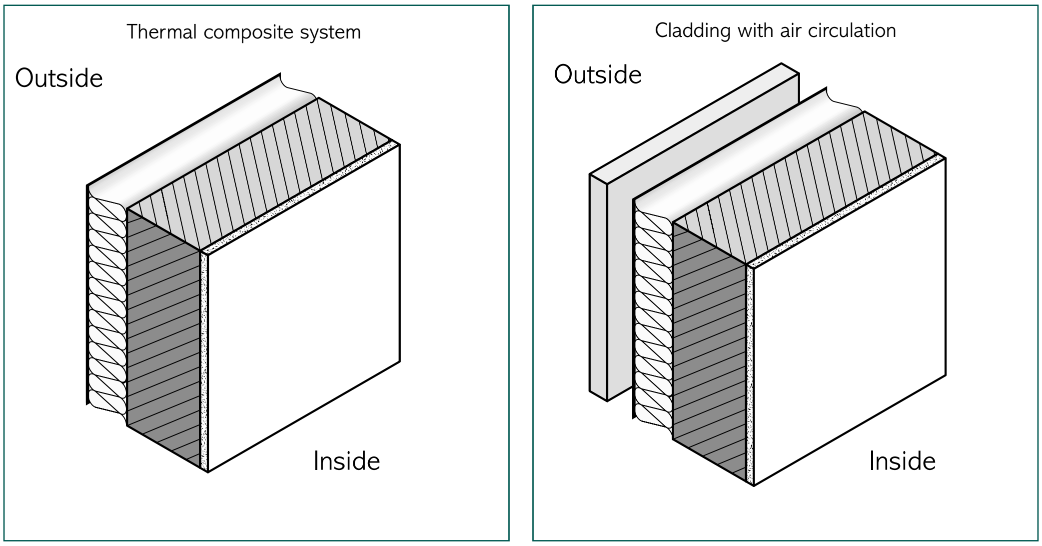
3.1.1 External insulation

> Description of the measure

The insulation is attached on the outer surface of the external wall (see Figure 4). This method is applied in many cases of retrofit projects and can be seen as one of the standard solutions in Europe. Generally two different types can be distinguished to increase external insulation during a retrofit:

- In a thermal composite system, the insulation material is attached to the wall and coated with a final layer. This method is widely employed in retrofit projects in central Europe
- A cladding with air circulation consists of insulation material, an air gap of approx 3 cm and a weatherproof layer (wood, metal sheets, ceramic plates etc.). Wood covered external insulation is commonly used in the Northern European countries.

***Figure 4:** Visuals of external insulation*



> Investment and Cost Analysis

As described in chapter 2.2.1 two different investment costs are taken into account:

- **Coupled realisation:** If the insulation is included in the framework of general renovation measures of the façade (e.g. a renewal of the surface) only the "additional investment" or "energy related investment costs" for insulation material and associated labour costs are taken into account as energy related costs.
- **Independent realisation:** If the insulation measure is carried out without any other maintenance measures carried out anyway, the total cost of the measure has to be taken into account.

Costs and characteristics of external insulation measures ("coupled" and "independent") are described in Table 7 for the 3 different climatic zones according to the desired level of the expert forecast for the EPB-standard (see introduction of chapter 3).

The basis for the cost calculations for the insulation measures in this study is a heat transmission coefficient (λ-value) of 0.04 W/mK[1] for the insulation layer. An average price has been assumed representing the mix of most representative insulation materials usually used in retrofit projects in Europe. The values employed here are normalized to one square meter of insulated wall.

Table 7: *Characteristics and investment cost external insulation in three climatic zones*

Façade: Investment external insulation		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	0.50	1.50	2.60
U-value after retrofit	[W/m²K]	0.17	0.38	0.48
Total investment costs	[€/m²]	152	92	70
Additional investment	[€/m²]	77	42	32

The variation of the investment costs for insulation measures in Europe mentioned in chapter 2.2.1 is due to the cost for external insulation: a decrease from higher prices in Northern Europe to lower prices in Southern Europe can be observed. This is caused by different labour costs and market conditions (e.g. VAT). Table 8 displays the economic assessment of retrofitting the façade with external insulation according to the expert forecast for the EPB-standards for three climatic zones.

[1] A normalised λ-value of 0.04 W/mK also includes the influence of thermal bridges for fixations, etc.

Table 8: *Economic assessment of external insulation in three climatic zones*

Façade: Results external insulation		cold zone	moderate zone	warm zone
Mitigation costs (independent)	[€/tCO_2]	585	9	-64
Mitigation costs (coupled)	[€/tCO_2]	146	-131	-166
Cost saved energy (independent)	[cent/kWh]	14.6	0.2	-1.3
Cost saved energy (coupled)	[cent/kWh]	3.5	-3.0	-3.4
Amortisation (independent)	[a]	50	18	13
Amortisation (coupled)	[a]	25	8	6

Mitigation costs and amortisation of increasing the external insulation of the façade to the expert forecast for the EPB-standards decrease from Northern to Southern Europe. The reason for this is the already relatively good energy-efficiency of the building stock in Northern countries. Nevertheless it needs to be emphasized that, due to the climate, buildings with poor insulation in colder areas offer economic opportunities to add insulation in retrofit measures.
In the moderate zone it is critical for the economic feasibility of external insulation of the wall to couple energy retrofit measures with renovation of the façade.
Whereas an independent improvement of the U-value of the façade is not cost-effective in most cases, a retrofit coupled to renovation proves to be economical.
In Southern Europe, comprehensive insulation is not common to date resulting in more potential for effective insulation improvements. Despite the warm climate considerable energy-savings can be achieved economically by improving the generally poor thermal resistance of the building stock in Southern Europe. However, this effect is not applicable to the hot Southern areas of the warm climatic zone, where no space heating is used.
It is concluded that it is imperative to strongly recommend that external insulation measures are coupled with maintenance of the façade in all climatic zones to obtain optimal cost-effectiveness.

> Economic optimum

Figure 5 demonstrates the effects on the U-value and CO_2 emissions and the financial implications (for independent and coupled measures) of façade external insulation as a function of additional insulation thickness.

The graphs on page 20 represent the resulting new U-values of the improved wall related to the additional insulation thickness. The insulation property (existing U-value) of the structures before the retrofit is taken into account in the calculation. The red line in the graphs marks the estimated retrofit level according to the expert forecast for the EPB-standards.

The graphs of the financial implications (on pages 21 and 22) display the annual overall costs resulting from the difference of annual capital costs and annual saved energy costs. If the thickness of insulation is increased all graphs show a minimum for the annual overall costs, representing the optimal insulation level. Due to the relatively flat minimum a wide range of insulation thicknesses leads to almost similar economic outcomes.

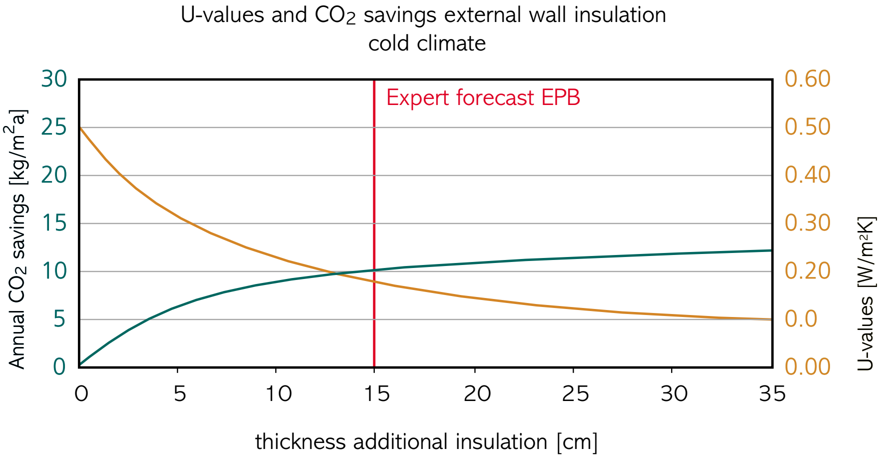
Analysing the results shows that for the cold zone external insulation is not cost-effective, either as a stand alone or as a coupled measure. This is due to the aforementioned relatively high insulation standard before retrofit in the cold zone. The overall annual cost does not decrease below the starting point (0 cm, no additional insulation). If insulation thickness is increased, an economic optimum can be reached between a U-value of 0.15 and 0.30 W/m^2K.
This also shows that the estimated U-value according to the predicted EPB-standard of 0.17 W/m^2K is already quite ambitious.

In moderate climates, independent insulation measures are almost cost-effective, with an optimum at a U-value of approx 0.20 – 0.40 W/m^2K. Beneath and above this insulation level a retrofit is generally not cost-effective. When looking at a coupled measures in moderate climates in Europe, it becomes evident, that a clear financial benefit can still be realised with an optimum between a U-value of 0.20 – 0.40 W/m^2K. The estimated U-value according to the expert forecast for the EPB-standard of 0.38 W/m^2K can be seen as a good basis with economic potential for further improvements.

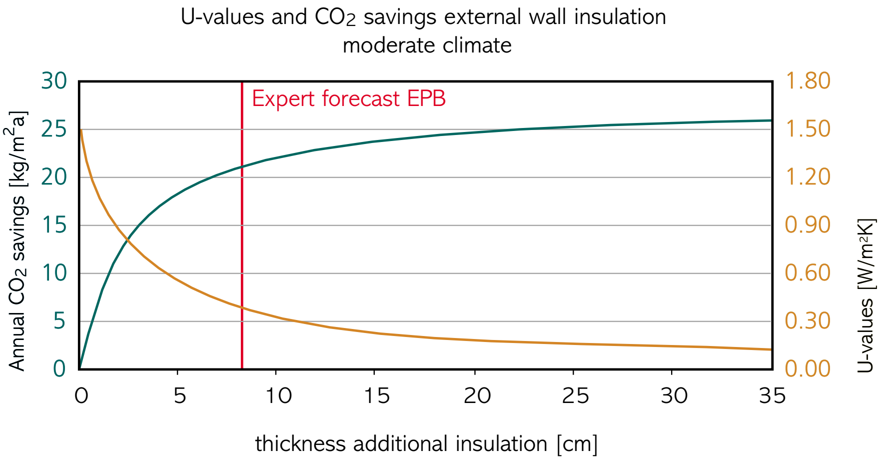
In Southern Europe the low thermal resistance of the average building envelope, makes even stand-alone insulation measures economically feasible. For this the economic optimum is near a U-value of approx 0.25 to 0.5 W/m^2K. The estimated U-value according to the expert forecast for the EPB-standard of 0.48 W/m^2K could therefore be further improved to reach a financial optimum.

***Figure 5a:** U-values and CO_2 savings*

Cold zone



Moderate zone



Warm zone

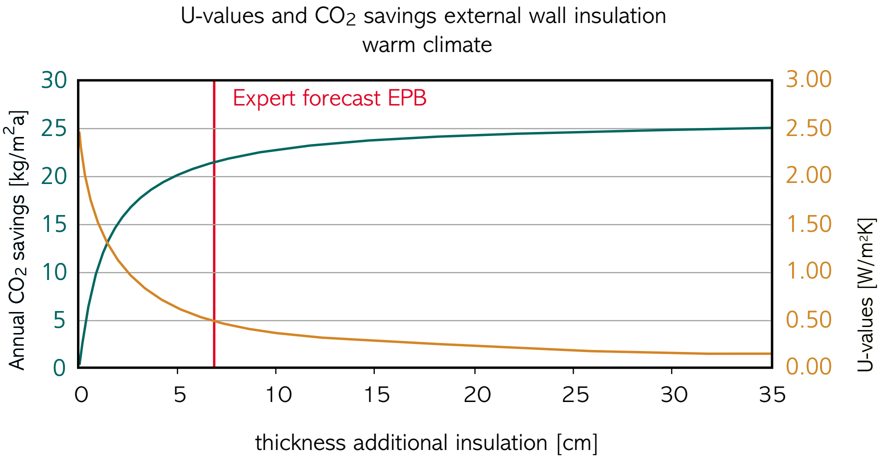
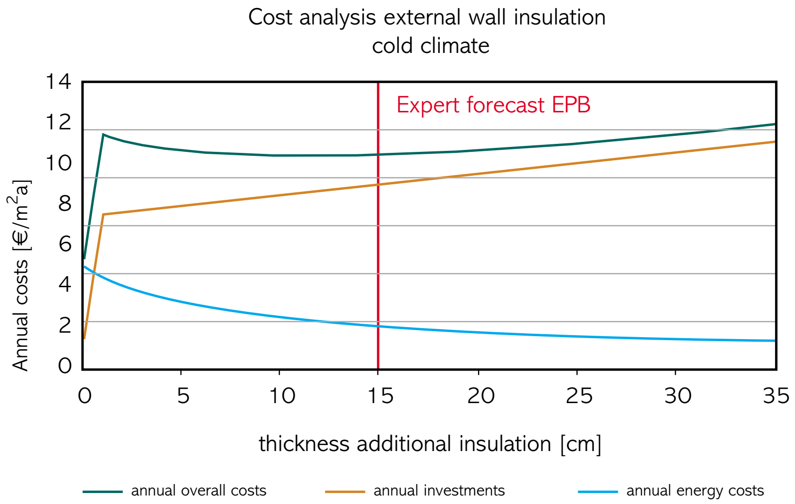
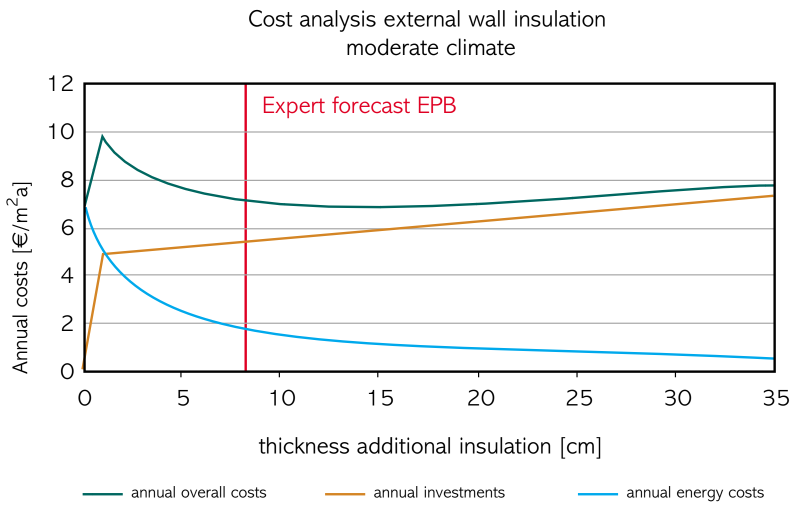


***Figure 5b:** Costs for Independent Measures*

Cold zone



Moderate zone



Warm zone

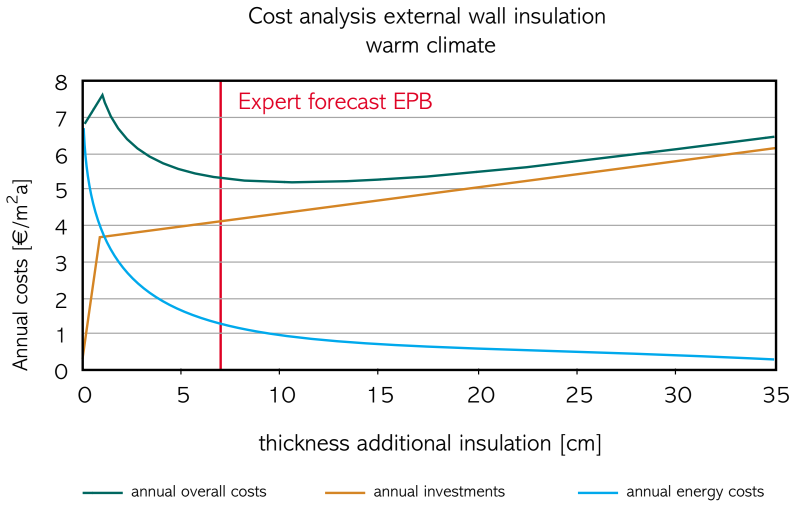
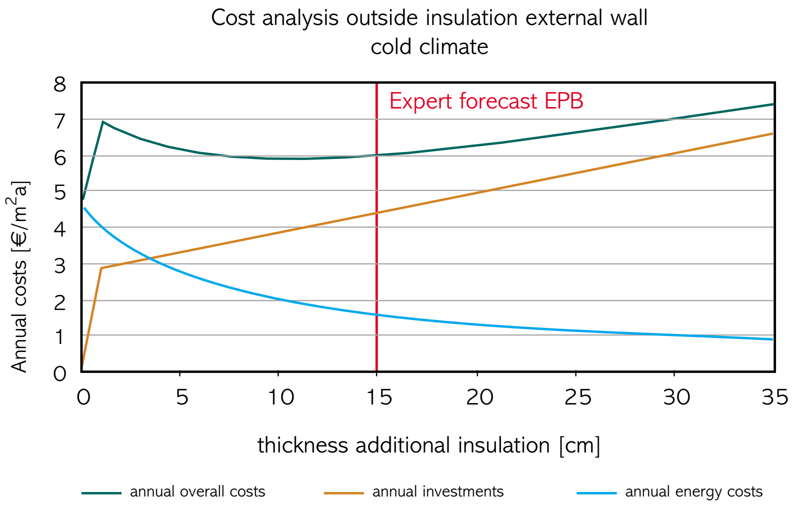
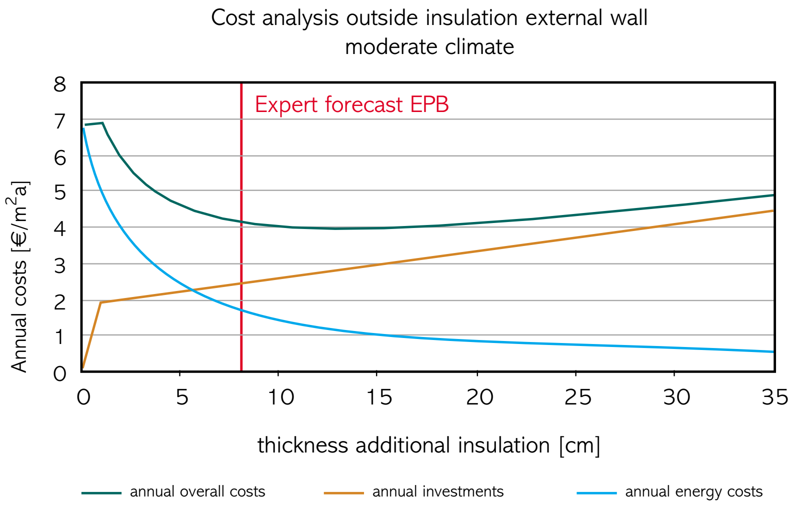


Figure 5c: *Costs for Coupled Measures*

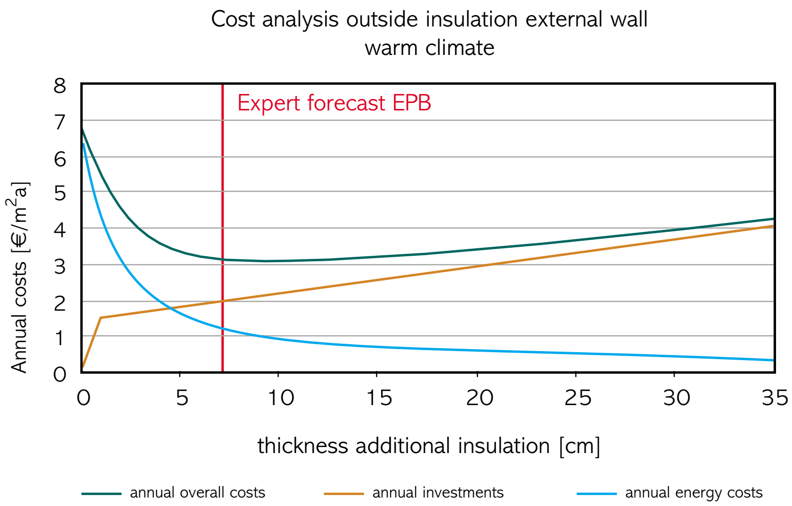
Cold zone



Moderate zone



Warm zone

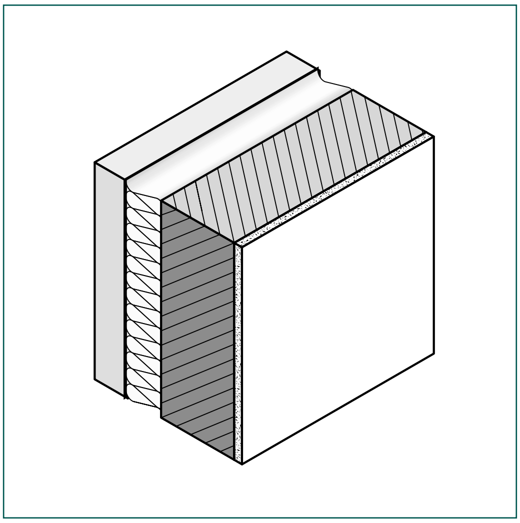


3.1.2 Cavity insulation

> Description of the measure

Walls with cavities (especially in older buildings) are most common in the Netherlands, the United Kingdom, Ireland and partly in Greece. In case of external walls with a cavity inside the structure, the insulation material can be applied by filling the existing cavity with insulation material (see Figure 6). This can be achieved, for instance, by removing several bricks of a cavity wall or by drilling small holes in the cross joints and blowing mineral wool, cellulose fibre or polystyrene beads into the gap. The thickness of the applied insulation material is limited to the width of the existing cavity (approx 5 - 10 cm). In younger buildings, cavities up to 15 cm can be found.

Figure 6: *Visual of Cavity Insulation*



> Investment and Cost Analysis

When applying cavity insulation as a retrofit measure, a coupling with renovation measures is not possible because the gap would otherwise remain untouched. In this case the total investment of the measure is to be seen as energy related. Costs and impact of cavity insulation measures according to the expert forecast for the EPB-standards are described in Table 9 and refer to one square meter of the insulated wall.

Table 9: *Characteristics and investment costs of cavity insulation in three climatic zones*

Façade: Investment cavity insulation		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	0.50	1.50	2.60
U-value after retrofit	[W/m²K]	0.17	0.38	0.48
Total investment costs	[€/m²]	41	21	17

Parallel to the cost profile of external insulation, higher prices in colder climates and lower investment costs in the warmer Southern countries can be observed. The investment costs per m^2 are considerably lower than for external insulation, because the most common technique of filling the gap by blowing insulation material is less labour intensive and consequently less cost intensive than attaching an external insulation. Table 10 displays the results of the economic assessment of retrofitting walls with cavity insulation according to the expert forecast for the EPB-standards for the three climatic zones.

Table 10: *Economic assessment of cavity insulation in three climatic zones*

Façade: Results Cavity Insulation		cold zone	moderate zone	warm zone
Mitigation costs	[€/tCO_2]	-63	187	-208
Cost saved energy	[cent/kWh]	-1.5	-4.3	-4.2
Amortisation	[a]	14	4	3

Investment cost for cavity insulation is comparably low in all the climatic zones examined making these measures economical.

> Economic Optimum

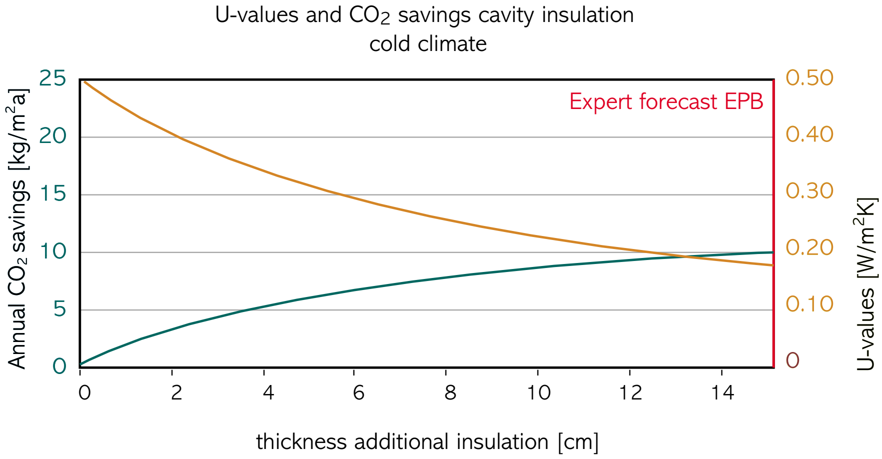
In Figure 7a, the effects on the U-value and CO_2 emissions and the financial implications (figure 7b) of cavity insulation of exterior walls are described, depending on the thickness of the additional insulation equivalent to the width of the existing gap. The red line marks the estimated retrofit level according to the expert forecast for the EPB-standards.

Due to the relatively low investment necessary for cavity insulation these measures are economic even with the already quite high standards in Northern Europe. An economic benefit can be reached when filling gaps starting from approx 4 cm, which is also the smallest width that can be found in the building stock, reaching a U-value of approx 0.3 W/m^2K. To reach the suggested insulation-standard however a cavity with a depth of 15 cm is necessary, and this is not always available.

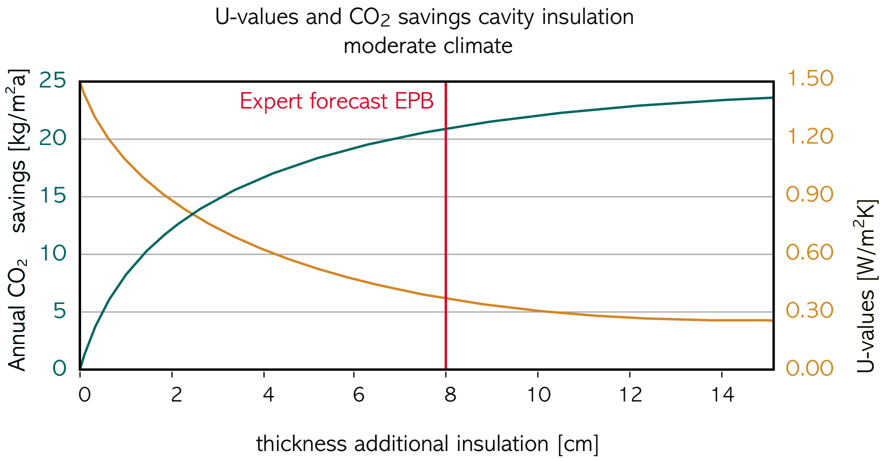
In moderate and warm climates cavity insulation is always cost-effective with increasing benefit and with larger cavities available. The estimated U-value of 0.38 W/m^2K (moderate zone) and 0.48 W/m^2K (warm zone) can be reached by filling gaps of 8 and 6 cm respectively, which is a quite common depth for external wall cavities. Larger gaps give the opportunity to improve beyond the expert forecast for the EPB-standards costs efficiently.

***Figure 7a:** U-value, CO_2 savings and economic Optimum of additional Cavity Insulation*

Cold zone



Moderate zone



Warm zone

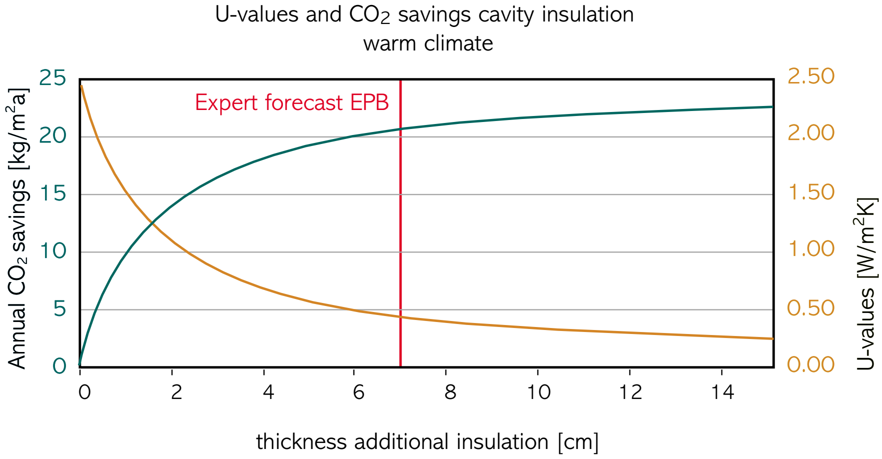
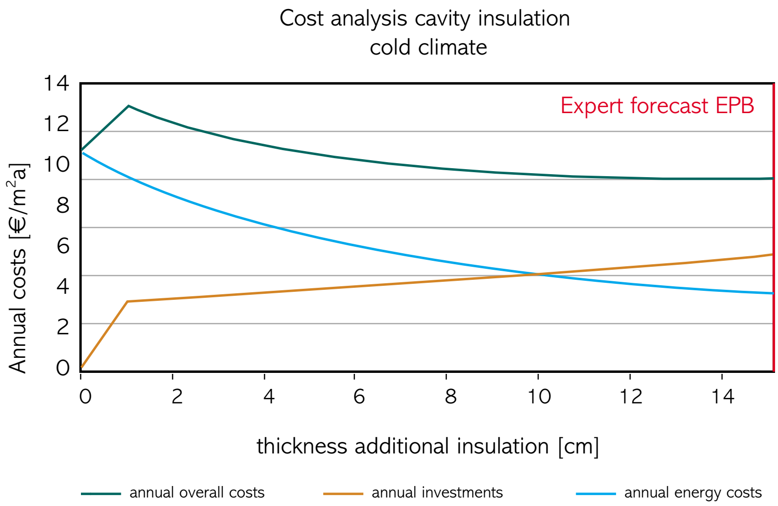
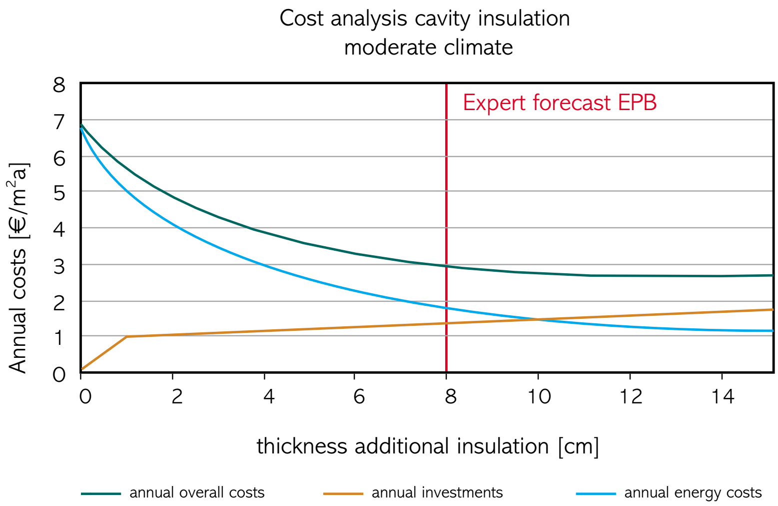


Figure 7b: *U-value, CO_2 savings and economic Optimum of additional Cavity Insulation*

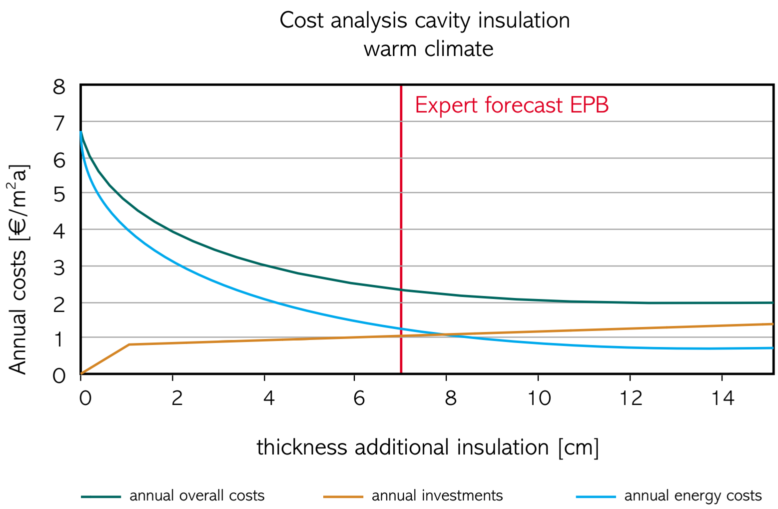
Cold zone



Moderate zone



Warm zone



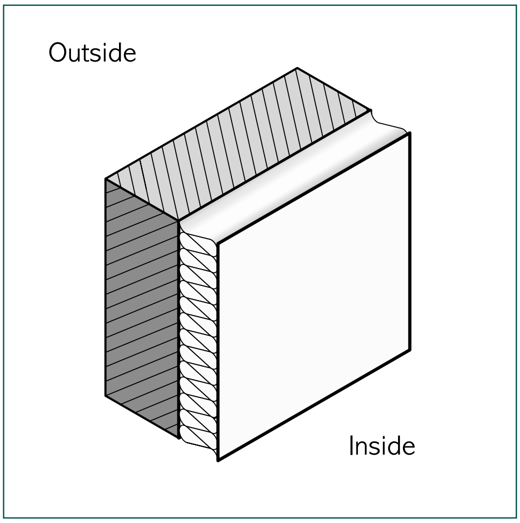
3.1.3 Interior insulation

> Description of the measure

Interior insulation is fixed to the inner surface of exterior walls (see Figure 8). This method is common in France and Ireland and also widely used in Greece.

However, in Northern European countries interior insulation is not usually used. Here, for existing buildings to meet the expert forecast for EPB-standards the use of approximately 16 cm of additional insulation would be required. For practical reasons (e.g. reduction of living area) the thickness of interior insulation is generally limited to a maximum of approx. 10 cm

Figure 8: *Visual of Interior Insulation*



> Investment and Cost Analysis

When interior insulation is applied as a retrofit measure this always results in redecoration, with wallpaper and paintwork, at least, being renewed. The cost of this has been subtracted from the total investment costs in the following calculations. Table 11, shows the cost and impact of interior insulation measures in moderate and warm climatic zones according to the expert forecast for the EPB-standards.

Table 11: *Characteristics and investment costs interior insulation in three climatic zones*

Façade: Investment interior insulation		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	uncommon	1.50	2.60
U-value after retrofit	[W/m²K]		0.38	0.48
Total investment costs	[€/m²]		32	23

The investment costs per m[2] for interior insulation are lower than for the more complex external insulation, but higher than cavity insulation, which is easier to apply.
Table 12 displays the results of the economic assessment for retrofitting external walls with interior insulation according to the expert forecast for the EPB-standards for the moderate and the warm climatic zones.

***Table 12:** Economic assessment of interior insulation in three climatic zones*

Façade: Results interior insulation		cold zone	moderate zone	warm zone
Mitigation costs	[€/tCO_2]	-	-159	-191
Cost saved energy	[cent/kWh]	-	-3.6	-3.9
Amortisation	[a]	-	6	4

In both climatic zones, interior insulation is a cost-effective measure when applied according to the expert forecast for the EPB-standard.

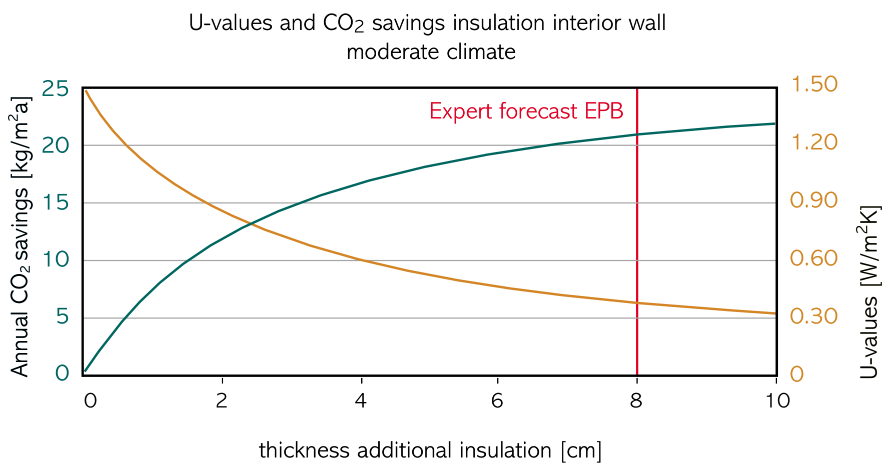
> Economic optimum

In Figure 9a the effects on the U-value and CO_2 emissions (left column) and the financial implications (right column) of interior insulation of the wall are described.

On the basis of the assessed insulation standard before retrofit in the moderate and warm climates interior insulation is always cost-effective. In both climate zones the assumed maximal thickness of the interior insulation (10 cm) leads to the economic optimum. This shows that the expert forecast for the EPB-standards (warm zone: 0.48 W/m²K = approx 6 cm, moderate zone; 0.38 W/m²K= approx 8 cm) is economically well balanced but could be further improved towards a technical maximum.

***Figure 9a:** U-values, CO_2 savings and economic optimum of additional Interior Wall Insulation in a moderate climatee*

Moderate zone



Moderate zone

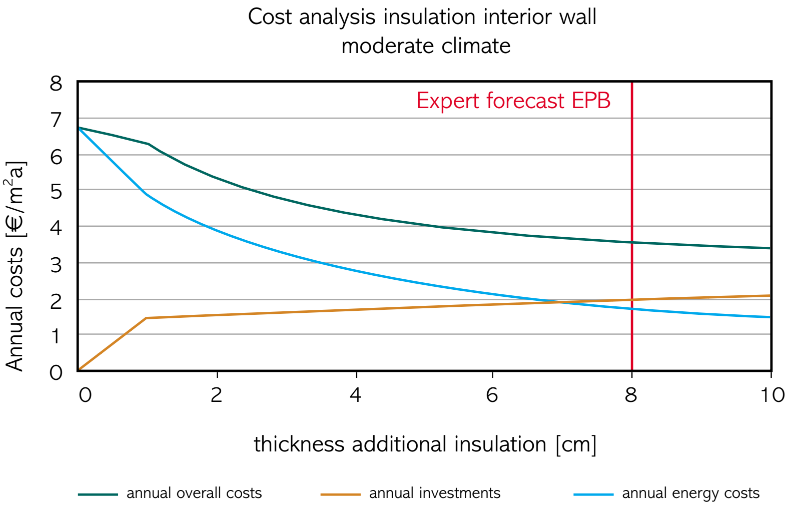
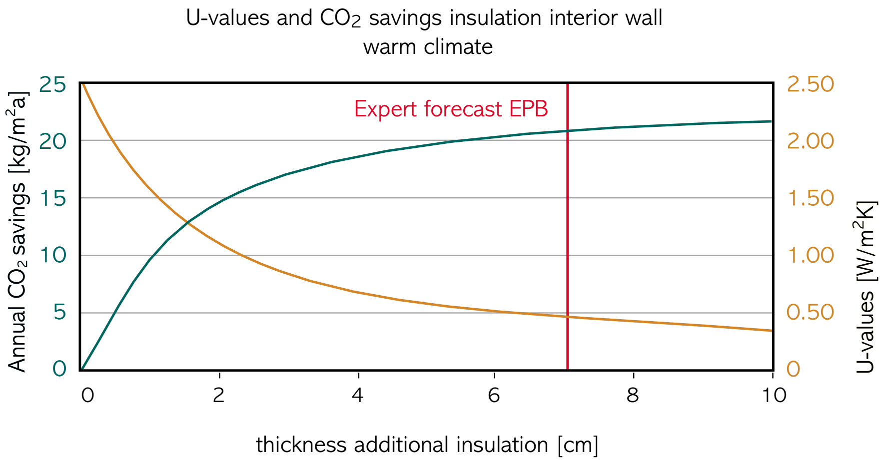
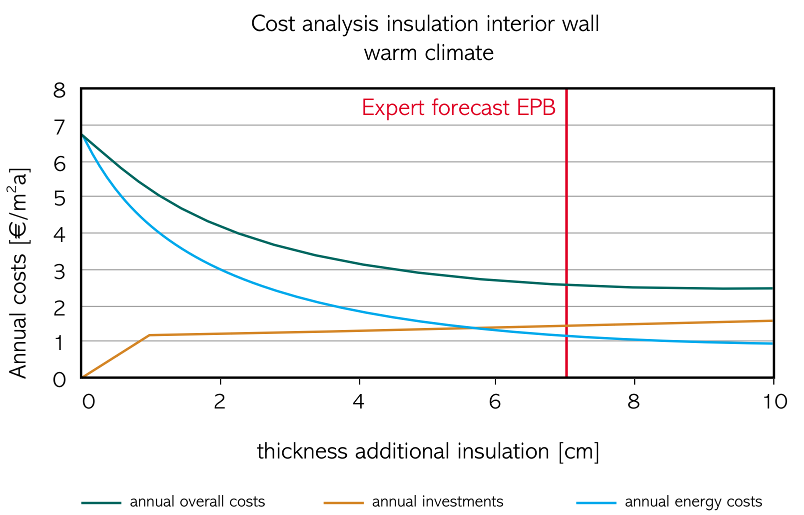


Figure 9b: *U-values, CO_2 savings and economic optimum of additional Interior Wall Insulation in a warm climate*

Warm zone



Warm zone



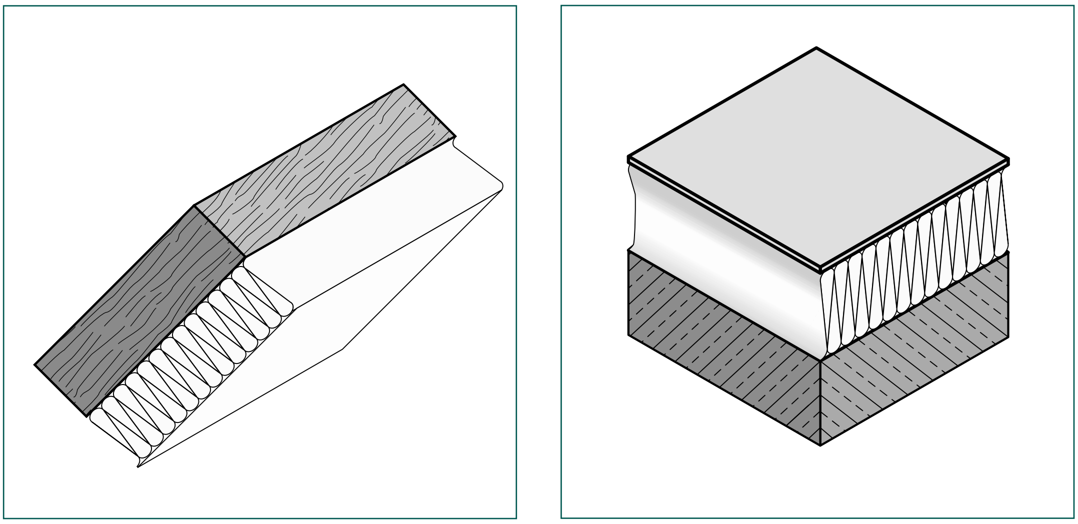
3.2 INSULATION OF ROOFS

> Description of the measure

When considering insulation of roofs during the thermal retrofit of buildings, two different types of roofs can be distinguished (see Figure 10).

- pitched roof: the additional insulation is usually added on the inside surface of the roof between rafters and, if the insulation thickness has to be further increased, beneath the rafters. The insulation of the roof is often combined with the conversion the attic (or loft) to living space which might increase the overall economic performance of the project. In other cases the attic is insulated horizontally between the ceiling joists ("cold roofs").
- flat roof: the insulation is applied to the exterior surface of the roof and is covered by a waterproofing layer.

Figure 10: *Visuals of Insulating methods for Pitched and Flat roofs*



> Investment costs

In the European building stock, single-family houses often have pitched or sloping roofs, whereas multi-family dwellings (flats, apartments) usually have flat roofs. Generally, more pitched roofs are found in Europe and their treatment is considered in the following calculations where additional insulation between rafters of pitched roofs is investigated. In this case it is not possible to reduce the additional investment costs by coupling the insulation measures with maintenance measures. The total investment has to be regarded as energy related. However, other solutions, e.g. the installation of prefabricated sandwich elements with integrated insulation might lead to reduced energy related costs when applied as part of the conventional retrofit cycle.

The cost and impact on U-values of insulation of the roof to achieve the expert forecast for the EPB-standards in the 3 different climate zones are detailed in Table 13. The costs are quoted for a section of one square meter of the insulated roof.

Table 13: *Characteristics and investment costs of additional roof insulation in three climatic zones*

Pitched Roof: Insulation investment		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	0.50	1.50	3.40
U-value after retrofit	[W/m²K]	0.13	0.23	0.43
Investment costs	[€/m²]	46	25	16

The measure is less expensive than interior insulation of walls because material and labour are less costly, especially if the loft is not converted for use as a living space.

Table 14 displays the results of the economic assessment for retrofitting the pitched roof to the levels of the expert forecast for the EPB-standards for three climatic zones.

Table 14: *Economic assessment of roof insulation in three climatic zones*

Pitched Roof: Results insulation		cold zone	moderate zone	warm zone
Mitigation costs	[€/tCO_2]	-61	-185	-222
Cost saved energy	[cent/kWh]	-1.5	-4.2	-4.5
Amortisation	[a]	14	4	2

Additional insulation to EPB-standards is cost-effective in all climatic zones, taking into account the insulation levels assumed to exist in roofs before retrofit. This is due to the relatively low investment required and the resulting large energy-savings.

> Economic optimum

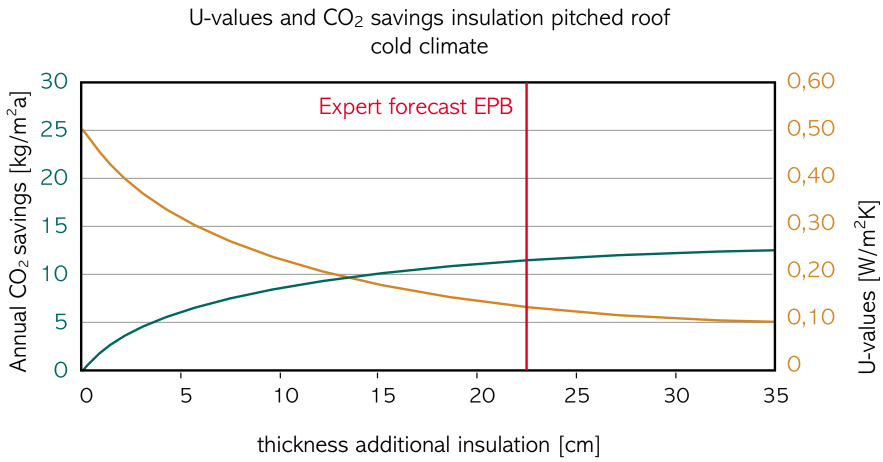
In Northern Europe, insulation of the roof is economic within an optimum insulation thickness range of approx 10-20 cm, leading to a U-value of 0.12 to 0.22 W/m²K (see Figure 11a). The EPB-standard is assessed to be 0.13 W/m²K and can therefore be seen as already of quite high performance.

In moderate climates a thermal retrofit of the roof is always cost-effective. The economic optimum can be reached with U-values between 0.32 and 0.14 W/m²K. This shows that the investigated EPB-standard of 0.23 W/m²K (approx 15 cm added) is economically well balanced but could be improved further.

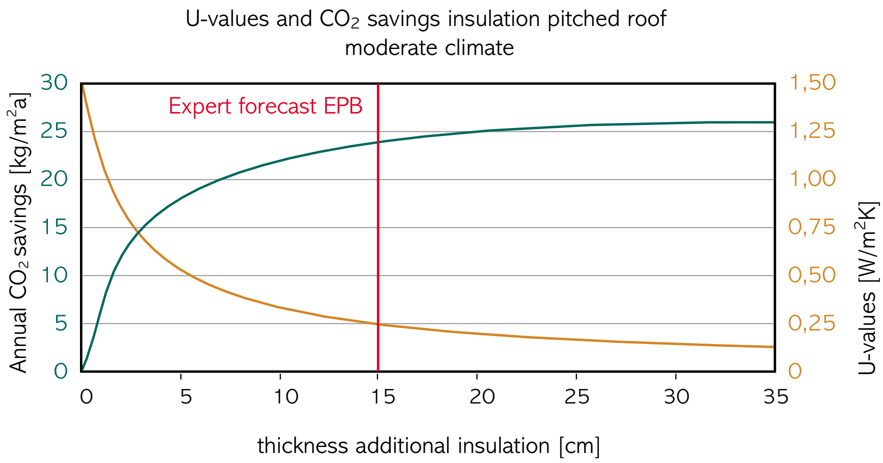
A comparable situation occurs in the warm climatic zone. The economic optimum there can be reached with U-values between 0.50 and 0.20 W/m²K. This shows that the further improvement of the U-value beyond the investigated EPB-standard of 0.43 W/m²K (approx 8 cm added) would lead to an economic and energy-efficiency optimum.

Figure 11a: *U-values, CO_2 savings and economic optimum of additional Roof insulation*

Cold zone



Moderate zone



Warm zone

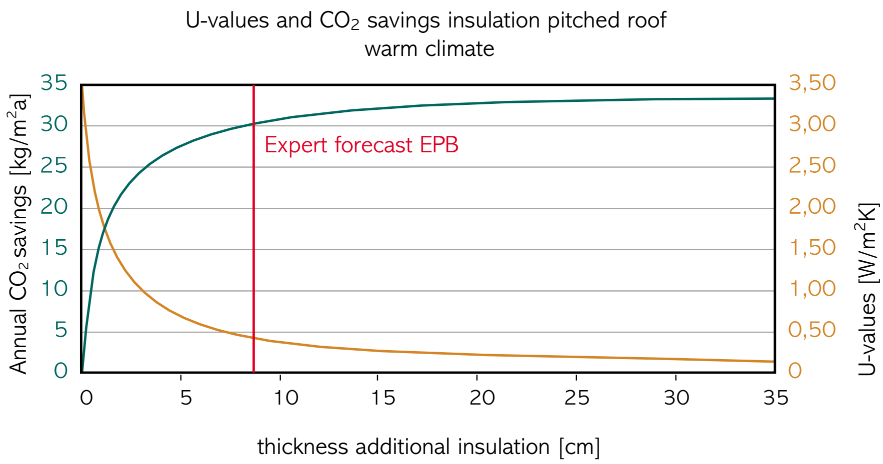
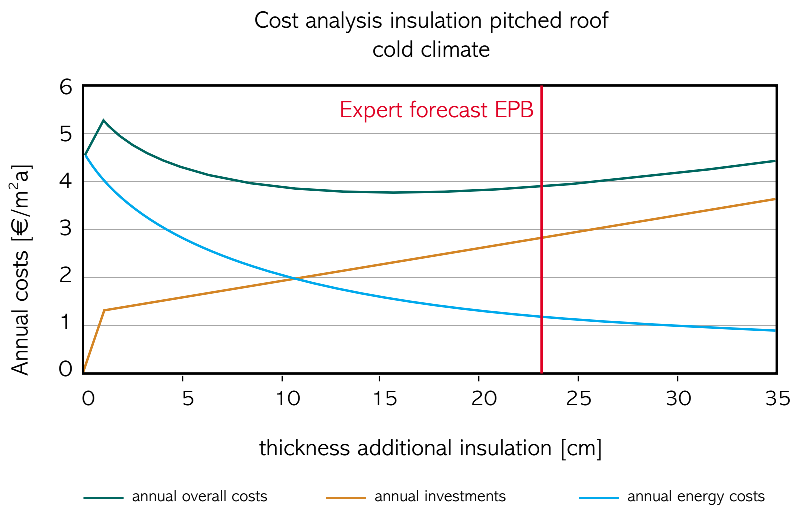
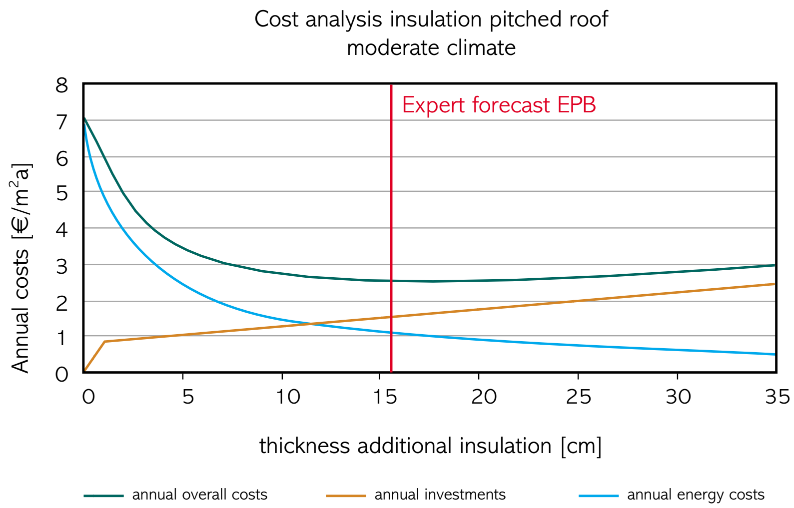


***Figure 11b:** U-values, CO_2 savings and economic optimum of additional Roof insulation*

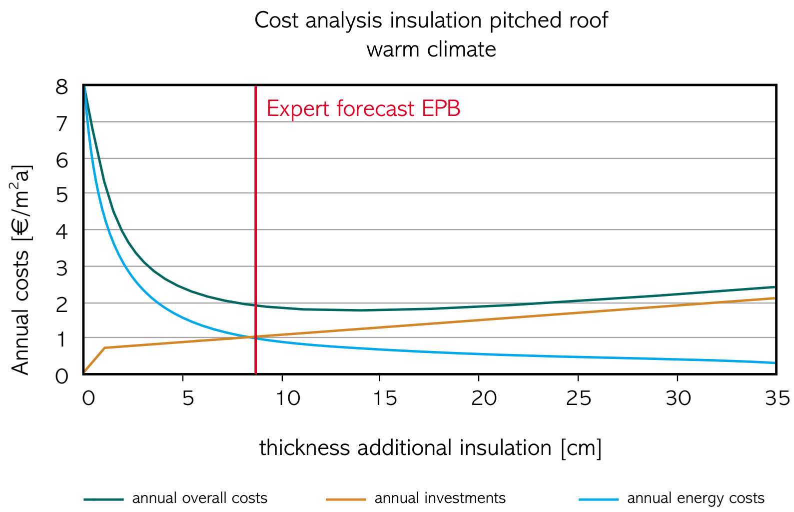
Cold zone



Moderate zone



Warm zone



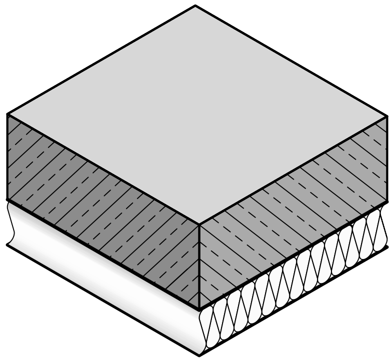
3.3 INSULATION OF GROUND FLOORS/CELLAR CEILINGS

> Description of the measure

The method of insulating the ground floor of a building during an insulation retrofit depends heavily upon whether the building has a cellar or not.

- In buildings with a cellar, the insulation can be applied under the cellar ceiling (see Figure 12) or, with more complex technical implications, on top of the ground floor
- In buildings without a cellar, it is sometimes possible to use crawl spaces in the structure (i.e. in wooden houses) or underneath the ground-floor for additional insulation.

Figure 12: *Visual of Insulation of the cellar ceiling*



> Investment costs

The following economic analysis is calculated for insulation of the cellar ceiling, which is the most common retrofit project for houses with a cellar. It is not possible to couple the insulation with maintenance measures because the cellar ceiling is normally not subjected to maintenance activities. The total investment of the measure has therefore to be regarded as energy related.

Cost and impact on U-values of insulation of the ground floor to the levels of the expert forecast for the EPB-standards in the 3 different climate zones are shown in Table 15. The costs are quoted for a one square meter section of the insulated floor.

Table 15: *Characteristics and investment costs of insulation of cellar ceiling in three climatic zones*

Cellar Ceiling: Investment insulation		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	0.50	1.20	3.40
U-value after retrofit	[W/m²K]	0.17	0.41	0.48
Investment costs	[€/m²]	44	22	18

Measures taken and the resulting costs can be compared to an insulation of a pitched roof.

Table 16 displays the economic assessment of insulating the cellar ceiling to the levels of the expert forecast for the EPB-standards for three climatic zones.

Table 16: *Economic assessment of insulation of cellar ceiling in three climatic zones*

Cellar Ceiling: Results insulation		cold zone	moderate zone	warm zone
Mitigation costs	[€/CO_2]	179	-79	-148
Cost saved energy	[cent/kWh]	4.4	-1.8	-3.0
Amortisation	[a]	27	12	7

Due to the existing high insulation standard in Northern Europe before retrofit, insulation of the ground floor to the levels of the expert forecast for the EPB-standards is not cost-effective. In moderate and warm climatic zones the additional insulation results in an economic benefit.

> Economic optimum

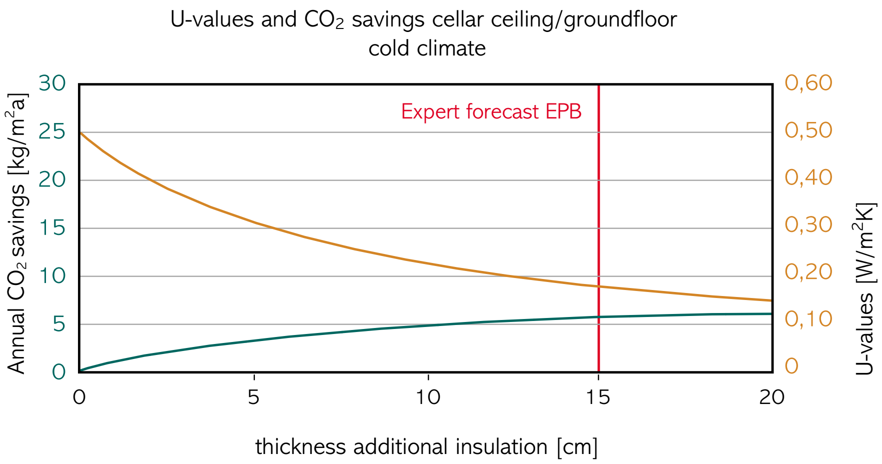
Due to the existing high insulation standard in Northern Europe retrofitting additional insulation is usually not cost-effective (see Figure 13a). The U-value of 0.17 W/m²K according to the expert forecast for the EPB-standards is already quite a high standard.

In moderate climates, retrofitted insulation of the floor is cost-effective within an optimum range of approx 0.25 – 0.50 W/m²K. The U-value of 0.38 W/m²K according to the expert forecast for the EPB-standards is a good basis but can be improved further.

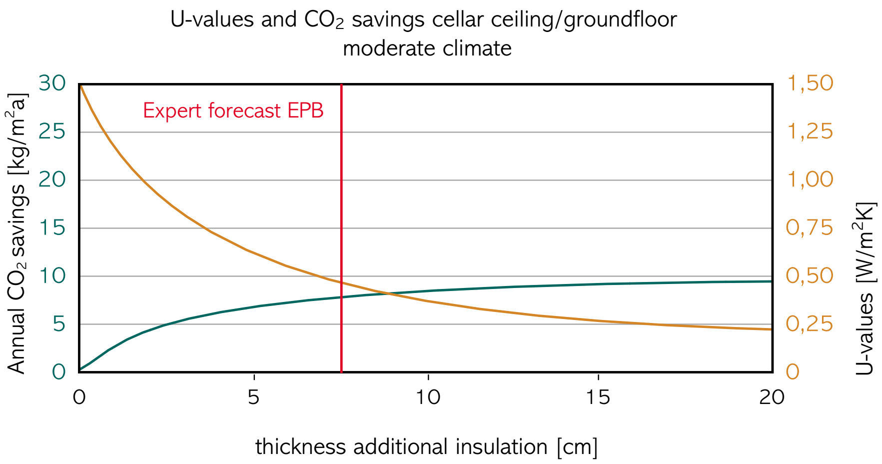
In Southern Europe, the low thermal resistance of the average building envelope makes floor insulation likely to be economically feasible with an optimum U value range between approx 0.40 to 0.70 W/m²K. The U-value of 0.48 W/m²K according to the expert forecast for the EPB-standards is close to the financial optimum.

Figure 13a: *U-values, CO_2 savings and economic optimum of additional insulation the cellar ceiling*

Cold zone



Moderate zone



Warm zone

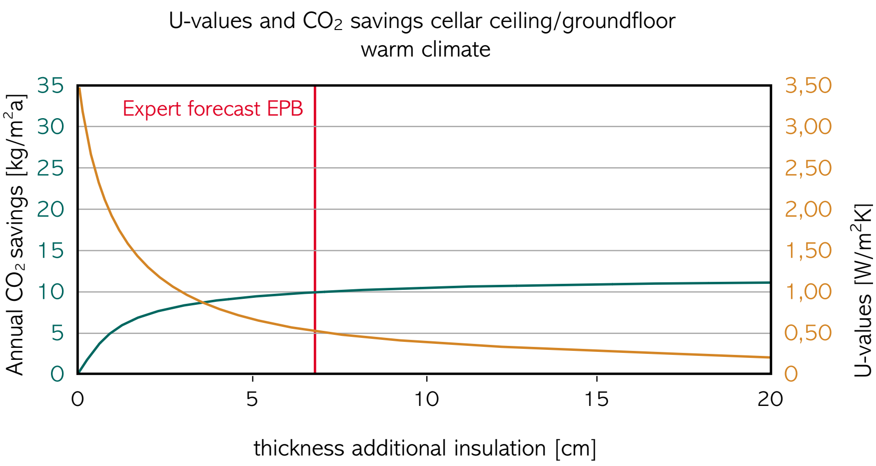
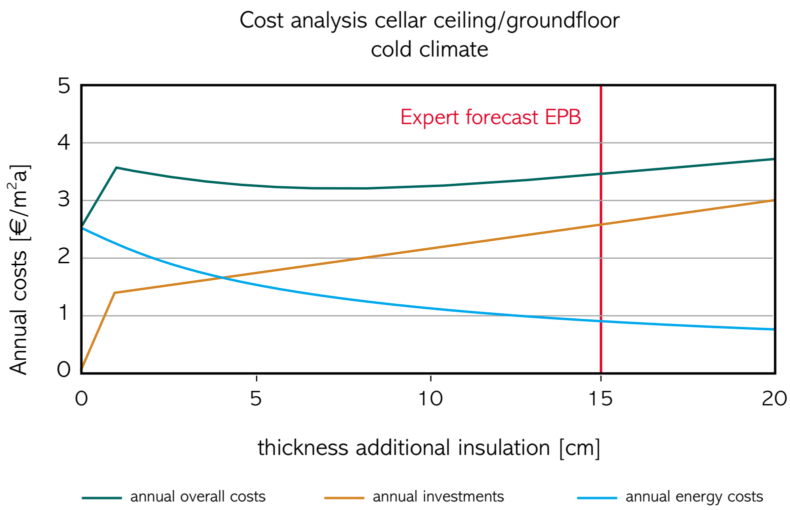
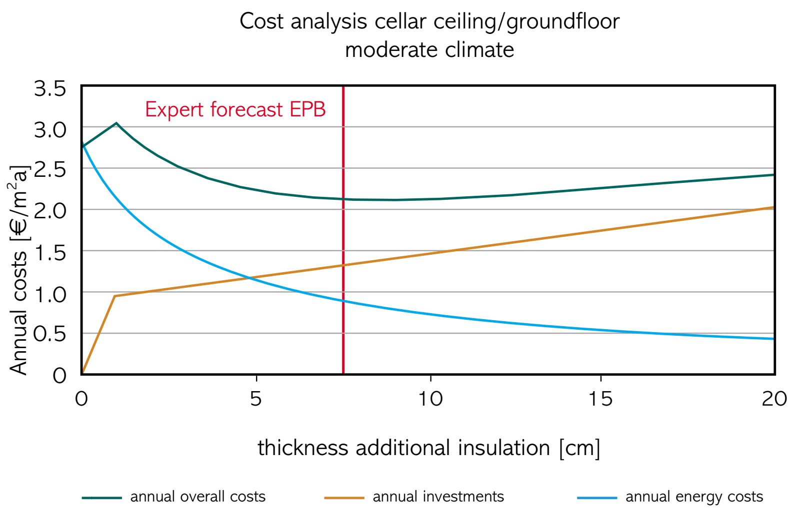


***Figure 13b:** U-values, CO_2 savings and economic optimum of additional insulation the cellar ceiling*

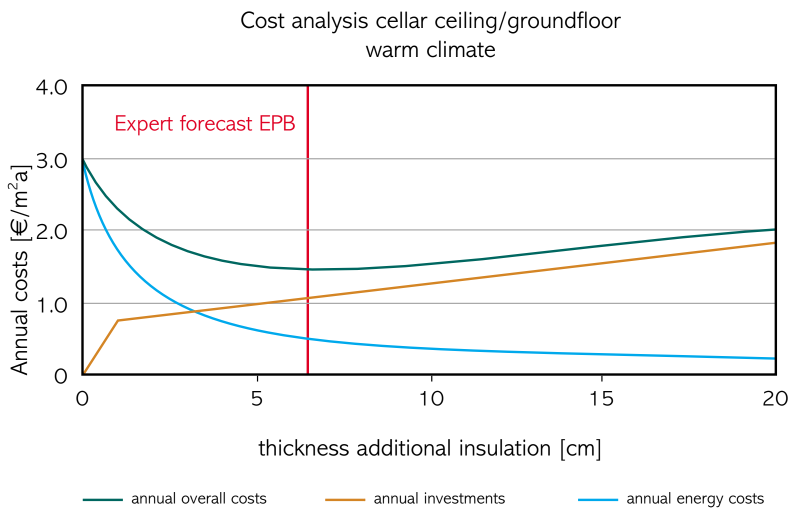
Cold zone



Moderate zone



Warm zone



3.4 WINDOWS

> Description of the measure

The windows of a residential building usually cover 20 to 30% of the façade. Therefore the thermal resistance of windows is of great importance. Their U-values range from approx 4.2 W/m^2K in old buildings with single panes to 0.7 W/m^2K for the current best available technology in Europe. This suggests the opportunity for major energy-efficiency improvements.

Windows are also characterised by their g-value. This describes the fraction of solar energy that passes through the glazing, providing heat gains and reducing energy demand for heating. Normally the g-value decreases with improving (reduced) U-value of the window. However, the decreased U-value usually overcompensates the decline in the g-value leading to an energy improvement. In warm climates, a lower g-value can be seen as favourable since the risk of overheating in the building is decreased.

The following glazing types can be distinguished (with declining U-value):

- Single glazing (only in old buildings)
- Double glazing
- Double glazing with gas filling (i.e. Argon) or coating
- Triple glazing

Window frames can be characterized by their U-value and the material used (i.e. wood, aluminium or PVC). Depending on the quality of frame and glazing, a total U-value for a window can be determined.

The thermal performance of the windows can be improved during a retrofit of a building in two ways:

- Exchange of the glazing only. This method can only be applied, if the window frames are in a good condition and should be accompanied by a renewal of the seals;
- The exchange of the total window allows improvement of the thermal performance of frame and glazing in one step.

> Investment cost

In this report, it is assumed that the exchange of the total window is usually undertaken. However, the replacement of the window can be carried out as an independent energy-efficiency measure or as a coupled measure when the windows/frames are in poor condition and have to be replaced. The replacement cost of the windows to the minimum requirements of the building regulations in the respective country are taken into account as non-energy related costs. Additional costs to meet the expert forecast for the EPB-standards are treated as energy-related costs.

The estimated costs and the impact on U values of the exchange of windows in the 3 different climate zones are shown in Table 17, and are normalised to a one square meter section of the replaced windows.

Table 17: *Characteristics and investment costs of improved windows in three cliamtic zones*

Windows: Investment replacement		cold zone	moderate zone	warm zone
U-value before retrofit	[W/m²K]	3.0	3.5	4.2
U-value after retrofit	[W/m²K]	1.33	1.68	2.71
Total investment costs	[€/m²]	433	316	142
Additional investment	[€/m²]	133	116	60

The total investment costs as well as the energy related costs for a replacement of windows are considerably higher than for insulation of the wall, roof or floor. Table 18 shows the economic assessment of the effects of improved windows to meet to the expert forecast for the EPB-standards.

Table 18: *Economic assessment of improved windows in three climatic zones*

Windows: Results replacement		cold zone	moderate zone	warm zone
Mitigation costs (independent)	[€/tCO_2]	200	300	295
Mitigation costs (coupled)	[€/tCO_2]	-151	-46	-23
Cost saved energy (independent)	[cent/kWh]	4.9	6.9	6.0
Cost saved energy (coupled)	[cent/kWh]	-3.7	-1.1	-0.5
Amortisation (independent)	[a]	29	38	37
Amortisation (coupled)	[a]	8	14	16

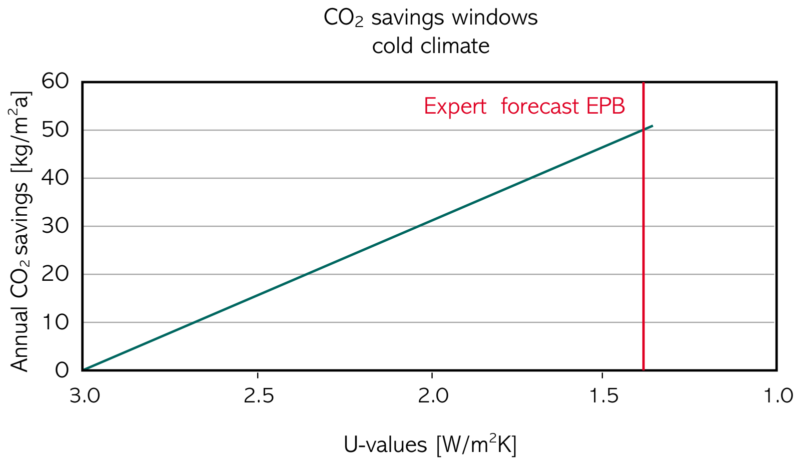
The economic benefit of the replacement of windows depends very heavily on whether the measure is carried out as an independent thermal efficiency measure or as a coupled action. An independent measure is usually not cost-effective whereas, it is economically viable in all climatic zones to install energy efficient windows where this is part of a necessary replacement within the renovation cycle. In many countries the market has already reacted and provides only energy efficient double glazing with coating or gas filling, as standard.

> Economic optimum

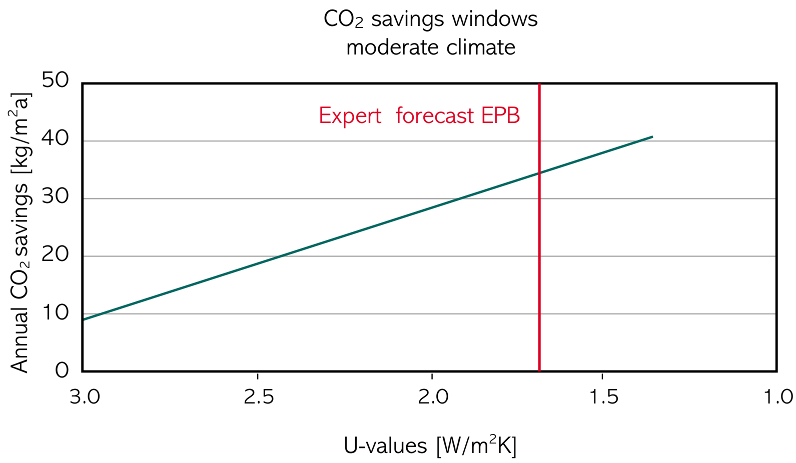
Figure 14a shows the yearly costs of a coupled replacement in the three climatic zones referred to one m² of replaced window area. It can be seen that the predicted standard is already quite ambitious in Northern Europe but that there is still room for economic and energy-efficiency improvement in Central and Southern Europe.

***Figure 14a:** U-values, CO_2 savings and economic optimum for improved windows*

Cold zone



Moderate zone



Warm zone

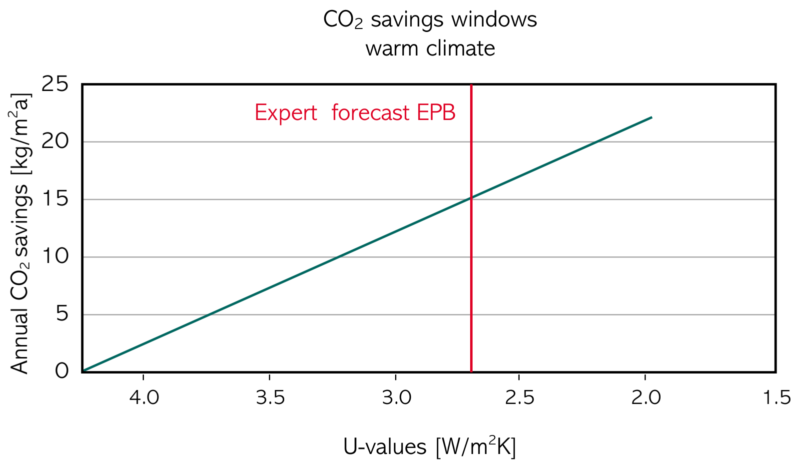
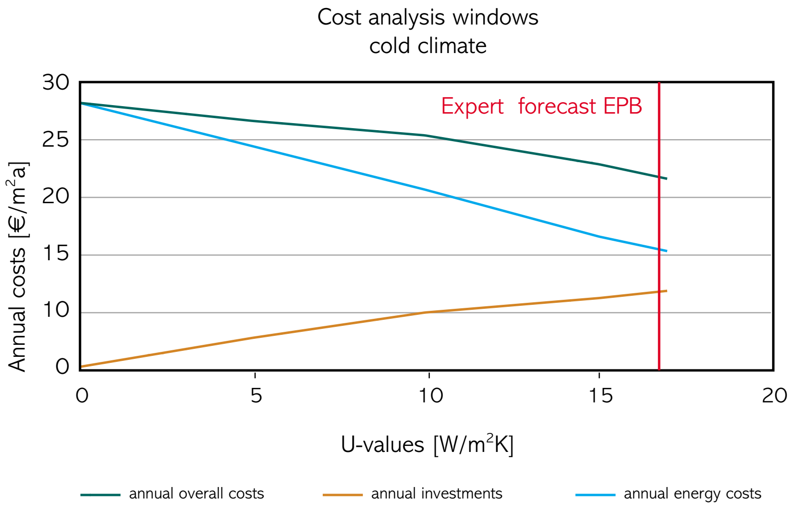
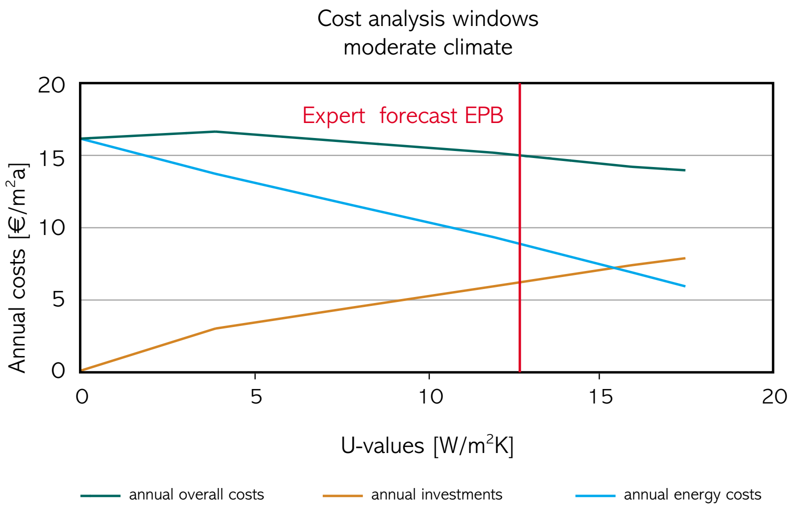


***Figure 14b:** U-values, CO_2 savings and economic optimum for improved windows*

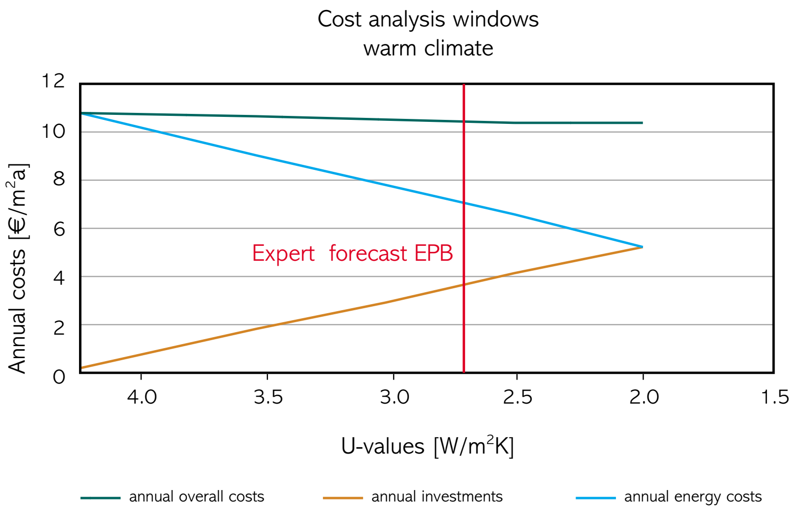
Cold zone



Moderate zone



Warm zone



3.5 HEATING

> Description of the measure

The reduction of CO_2 emissions from a heating system can be achieved either by a fuel switch to an energy carrier with a lower CO_2 emission-factor (i.e. fuel switch from electric to gas-heating) or by the replacement of an old boiler with a new, more efficient system. The latter will be investigated further assuming that the building envelope was already improved to the levels of the expert forecast for the EPB-standards. This approach reflects the fact that it is more feasible to reduce the energy demand of a building before installing a properly designed new heating system. The other way around the capacity of a new heating system would be oversized after retrofitting the building envelope. In moderate and warm climates, gas fired systems have the largest market share and are therefore used as the basis of the following calculations.

Economically it is especially important whether work is carried out on a heating system just to make it more energy efficient or whether this takes place as part of a replacement due to age or reliability.

> Replacement of gas boilers as an energy-efficiency measure only

In the first place, the effect of replacing of an existing gas boiler by a standard gas boiler is assessed for an apartment block. In this, the production of domestic hot water is taken into account. An improvement of the heating system also affects the usually combined supply of domestic hot water. Individual heating and district heating were not considered.

In Table 19 a decline in investment costs from Northern to Southern European countries is again apparent.

Table 19: *Characteristics and investment for independent efficiency improvements of heat production in multi-family houses in three climatic zones*

Investment Heat generation: Independ. Replacement (Standard boiler)		cold zone	moderate zone	warm zone
Efficiency before retrofit (not renovated)[1]	[η %]	78	78	78
Efficiency after retrofit (standard boiler)	[η %]	85	85	85
Total investment costs (standard boiler)	[€]	17,500	14,200	11,200

Table 20 shows that, in any climatic zone, the replacement of a boiler in an apartment block just for energy-efficiency reasons is not cost-effective due to the relatively large investment required. Considering the higher investment cost per m² of living area for a new heating system in a single-family house this leads to the conclusion that replacement of the gas boiler is even less cost-effective in a single-family house unless required for maintenance purposes.

[1] all factors are related to the lower heating value (LHV, not including condensation energy)

***Table 20:** Economic assessment of independent efficiency improvements of heat production in multi-family houses in three climatic zones*

Results Heat generation: Independent replacement (Standard boiler)		cold zone	moderate zone	warm zone
Mitigation costs (independent)	[€/tCO_2]	20	15	37
Cost saved energy (independent)	[cent/kWh]	0.4	0.3	0.8
Amortisation (independent)	[a]	15	14	16

> Coupled replacement of gas boilers in multi-family houses

In a second step, the results of an improvement in the efficiency of the heating system coupled with an otherwise necessary replacement are assessed by exchanging a standard boiler in the old system by a condensing boiler in the new. The difference in investment between a standard and a condensing boiler is considered an energy related cost.

***Table 21:** Characteristics and investment for coupled efficiency improvements of heat production in multi-family houses in three climatic zones*

Investment heat generation: Coupled replacement (Condensing boiler)		cold zone	moderate zone	warm zone
Efficiency after retrofit (Standard)	[η %]	85	85	85
Efficiency after retrofit (Condensing)	[η %]	97	97	97
Energy related investment costs	[η €]	1,200	1000	1,600

For energy-efficiency improvements to the building envelope described in the previous chapters a general decrease of investment cost was visible from Northern to Southern countries. A reverse trend can be seen in the investment cost for condensing boilers (Table 21). This is caused by the low market share of such boilers in warm climate, whereas these systems became standard in the moderate and warm climate zone.

***Table 22:** Economic assessment of coupled efficiency improvements of heat production in multi-family houses in three climatic zones*

Results heat generation: Coupled replacement (Condensing boiler)		cold zone	moderate zone	warm zone
Mitigation costs (coupled)	[€/tCO_2]	-216	-217	-164
Cost saved energy (coupled)	[cent/kWh]	-4.4	-4.4	-3.3
Amortisation (coupled)	[a]	2	2	5

Table 22 shows that, for all climatic zones, where replacement of a gas heating system is required due to age or maintenance the installation of a condensing boiler in large multi-occupancy buildings is very cost-effective due to the relatively low additional energy related investment cost.

> Coupled replacement of gas boilers in single-family houses

In order to verify whether this last conclusion is also valid for smaller houses the assessment of similar measures for a terraced house are displayed in Table 23.

Table 23: *Economic assessment of coupled efficiency improvements of heat production in single-family houses in three climatic zones*

Results heat generation: Coupled replacement (Condensing boiler)		cold zone	moderate zone	warm zone
Energy related investment costs	[€]	400	325	540
Mitigation costs (coupled)	[€/tCO_2]	-97	-116	48
Cost saved energy (coupled)	[cent/kWh]	-2.0	-2.3	1.0
Amortisation (coupled)	[a]	8	7	16

The results show that in cold and moderate climates the coupled replacement of an old energy supply system by a condensing boiler results in an economic benefit. In Southern Europe coupled replacement is nearly cost-effective and could become so if market prices for condensing systems decrease in the future due to higher market penetration

3.6 OVERVIEW OF ENERGY-EFFICIENCY MEASURES

Table 24 - 26 summarises the evaluations of measures to reduce the heat energy consumption, which could become standard in the three investigated climate zones by the time the EPB Directive is implemented into national legislation. The results show that most of the measures can be carried out cost-effectively, especially in the warm and moderate climatic zones.

Table 24: *Overview of individual energy-saving measures in the cold climatic zone*

Cold zone	Insulation					Replacement	
	Wall external	Wall cavity	Wall interior	Pitched roof	Floor	Windows	Boilers[1]
Mitigation costs (Independent) [€/tCO_2]	585	-63	-	-6.1	179	200	20
Mitigation costs (Coupled) [€/tCO_2]	146	-63	-	-	-	-151	-216
Cost saved energy (Independent) [cent/kWh]	14.6	-1.5	-	-1.5	4.4	4.9	0.4
Cost saved energy (Coupled) [cent/kWh]	3.5	-1.5	-	-	-	-3.7	4.4
Amortisation (Independent) [a]	50	14	-	14	27	29	15
Amortisation (Coupled) [a]	25	14	-	-	-	8	2

Table 25: *Overview of individual energy-saving measures in the moderate climatic zone*

Moderate zone	Insulation					Replacement	
	Wall external	Wall cavity	Wall interior	Pitched roof	Floor	Windows	Boilers[1]
Mitigation costs (Independent) [€/tCO_2]	9	-187	-	-185	-79	300	15
Mitigation costs (Coupled) [€/tCO_2]	-131	-187	-159	-	-	-46	-217
Cost saved energy (Independent) [cent/kWh]	0.2	-4.3	-	-4.2	-1.8	6.9	0.3
Cost saved energy (Coupled) [cent/kWh]	3.0	-4.3	-3.6	-	-	-1.1	-4.4
Amortisation (Independent) [a]	18	4	-	4	12	38	14
Amortisation (Coupled) [a]	8	4	6	-	-	14	2

Table 26: *Overview of individual energy-saving measures in the warm climatic zone*

Warm zone	Insulation					Replacement	
	Wall external	Wall cavity	Wall interior	Pitched roof	Floor	Windows	Boilers[1]
Mitigation costs (Independent) [€/tCO_2]	-64	-208	-	-222	-148	295	37
Mitigation costs (Coupled) [€/tCO_2]	-166	-208	-191	-	-	-23	-164
Cost saved energy (Independent) [cent/kWh]	-1.3	-4.2	-	-4.5	-3	6.0	0.8
Cost saved energy (Coupled) [cent/kWh]	-3.4	-4.2	-3.9	-	-	-0.5	-3.3
Amortisation (Independent) [a]	13	3	-	2	7	37	16
Amortisation (Coupled) [a]	6	3	4	-	-	16	5

[1] As independent replacement the installation of conventional gas boilers in multi-family houses is assessed. The coupled replacements compares the additional costs and energy-savings of a condensing boiler to a conventional boiler.

4] THE ASSESSED RETROFIT PACKAGES

Up to this point, the report has considered the effects of applying single measures during the retrofit of buildings. However, the combination of these measures offers the possibility of maximising the economics of retrofit measures while reducing the overall energy consumption in the building stock. E.g. due to insulation the maximal heat-load capacity decreases and a smaller heating system can be installed. To reach an optimal performance, the combination of single measures to suitable packages has to follow the principle of Trias Energetica which is defined by 3 steps:

1. limit demand for energy through rational use of energy,
2. use renewable energy to fulfil remaining demand, if possible, and
3. use fossil fuels, if necessary, as efficient and as clean as possible

Following this approach the improvement of the insulation levels can be seen as an important prerequisite for energy-efficient buildings. Therefore the investigated retrofit packages according to the expert forecast for the EPB-standards focus on the first principle, which would see a significant reduction of the energy demand for heating by the addition of insulation to the building envelope and the replacement of old with low U-value windows.

Step two, the use of renewable energies, is not taken into account as measure in the predicted EPB-retrofit packages. Renewable energies are an important part of innovative retrofit projects and are gaining substantial market share. However, the aim of the study was to assess the effect of the basic and most widely applied measures in the building stock in Europe.

Step three is taken by replacing an old existing heating system with a new condensing boiler with a significantly higher level of energy-efficiency.

In the following section of the report retrofit packages are described which are estimated to meet the expert forecast for the EPB-standards in the three climatic zones. Again the economic performance of the packages is assessed for independent and coupled actions.

4.1 DESCRIPTION OF STANDARD BUILDINGS

The effect of the retrofit packages is analysed for terraced houses and multi-family houses on the basis of the standard building types as used in the previous Ecofys reports [Ecofys 2002, Ecofys 2004]. The main characteristics of the model houses are described in Table 27. A detailed description is given in the annex.

Table 27: *Characteristics of the employed standards house types*

Standard building types	Terraced House	multi-family house
Dwelling units	1	16
Living area	120 m^2	1,637 m^2
Volume	421 m^3	5,374 m^3
Form factor A/V	0.64	0.38
Standard energy supply		
Cold climate	Electricity	District heating
Moderate climate	Gas boiler	Gas boiler
Warm climate	Gas boiler	Gas boiler

4.2 RETROFIT PACKAGES - COLD ZONE

The retrofit package for the Northern zone is concerned with the improvement of the building envelope. The U-values of walls, roofs, cellar ceilings and windows are reduced by additional insulation and a replacement of windows thus improving the already considerably high standard in Northern countries (see Table 28). The most common energy supply for single-family houses in Northern Europe is electricity. Apartment blocks are commonly supplied with district heating, the efficiency of which is determined by parameters outside of the considerations of this report. Also, assuming that the energy carrier remains the same, the heating system remains unchanged in the calculations for the cold climatic zone.

Table 28: *Details of retrofit actions (expert forecast EPB, cold zone)*

Cold zone			Before retrofit	After retrofit
Building envelope	U-value roof	[W/m²K]	0.50	0.13
	U-value façade	[W/m²K]	0.50	0.17
	U-value cellar-ceiling	[W/m²K]	0.50	0.17
Windows	U-value	[W/m²K]	3.00	1.33
	g-value	[W/m²K]	0.76	0.60
Energy supply	Electricity/district heat	Unchanged		

The retrofit packages described in table 28 lead to the results which are displayed in Table 29. Please note that the results for individual measures in section 3 relate to the surface area of the constructional element or in the case of the heating system, they refer to the assessed house type. In this section the results for the retrofit packages are normalised to the heated floor area of the house.

Table 29: *Economic assessment of retrofit actions (expert forecast EPB, cold zone)*

Investment and Results		Terraced House	Multi-family house
Total investment	[€/m²	287	204
Energy related investment	[€/m²]	145	87
End energy-savings	[kWh/m²a]	97	62
Mitigation costs (independent)	[€/t]	50	760
Mitigation costs (coupled)	[€/t]	-111	107
Cost saved energy (independent)	[cent/kWh]	2.6	12.7
Cost saved energy (coupled)	[cent/kWh]	-5.9	1.8
Amortisation (independent)	[a]	20	52
Amortisation (coupled)	[a]	10	22

Installing a retrofit package according to the standards of the expert forecast for the EPB independent from otherwise required maintenance measures is usually not cost-effective in the Northern zone. The possibility to couple the energy-efficiency retrofit with maintenance measures is provided when improving the facades (external insulation), windows and the energy supply system. Such measures account for the major part of the investment costs during a retrofit.

Coupled retrofit packages in Northern Europe are usually cost-effective in single-family houses due to the relatively high electricity prices for heating (compared to other energy sources), which improves the economic result of energy-saving measures. Multi-family (Apartments) houses are usually supplied with district heating, which is cheaper than electric heating. This leads to a lower financial benefit for the consumer of the saved energy. The retrofit package is therefore not cost-effective when applied to a multi-family (apartment) house with district heating in Northern countries.
Obviously the remaining buildings with poor insulation in cold climates offer economic opportunities to add insulation in retrofit measures.

It should be recognised that it is most important in the economic assessment of retrofit measures to analyse the actual situation in detail before retrofit since cost-effectiveness depends heavily on several factors including: the insulation level before retrofit; the exact investment costs for the retrofit measures (which might differ from the average values in this report due to specifics of the investigated project); the type of energy supply used and its corresponding price as well as the climatic conditions.

4.3 RETROFIT PACKAGES - MODERATE ZONE

The retrofit package for the moderate zone also begins with improvements to the building envelope (see Table 30). The U-values of walls, roofs, cellar ceilings and windows are significantly reduced by additional insulation and replacement of windows. A more efficient condensing boiler replaces the existing heating system.

Table 30: *Details of retrofit actions (expert forecast EPB, moderate zone)*

Moderate zone			Before retrofit	After retrofit
Building envelope	U-value roof	[W/m²K]	1.50	0.23
	U-value façade	[W/m²K]	1.50	0.38
	U-value cellar-ceiling	[W/m²K]	1.20	0.41
Windows	U-value	[W/m²K]	3.50	1.68
	g-value	[ ]	0.76	0.63
Energy supply (gas)	Annual efficiency	[η %]	78	97

The retrofit packages described in table 30 lead to the results given in Table 31. As for the assessment of the retrofit package in the cold climate zone the results are normalised to the heated floor area of the investigated house.

Table 31: *Economic assessment of retrofit actions (expert forecast EPB, moderate zone)*

Investment and Results		Terraced House	Multi-family house
Total investment	[€/m²]	207	133
Energy related investment	[€/m²]	86	53
Energy-savings	[kWh/m²a]	234	136
Mitigation costs (independent)	[€/t]	11	30
Mitigation costs (coupled)	[€/t]	-150	-144
Cost saved energy (independent)	[cent/kWh]	0.2	0.6
Cost saved energy (coupled)	[cent/kWh]	-3.0	-2.9
Amortisation (independent)	[a]	17	19
Amortisation (coupled)	[a]	7	8

Installing a retrofit package to the standards of the expert forecast for the EPB independent of otherwise required maintenance measures is usually not cost-effective in the moderate zone. However, coupled retrofit packages result in payback times of approx 7 years or approx 8 years for single-family or multi-family (apartments) house respectively, which make them cost-effective.

> Advanced Standard

The assessment of the individual measures in section 3 concludes that the expert forecast for the insulation levels in the moderate climate zone to achieve the EPB-standard are on the low side compared with the economic optimum. A possible “advanced standard” and its consequences are described in Table 32. The insulation levels used have been drawn from the optimisation graphs for individual measures in section 3. Results have been taken from the upper limit of the area in which the measures are most cost-effective.

Table 32: *Details of retrofit actions according to an “advanced standard”, moderate zone*

Moderate zone			Before retrofit	After retrofit
Building envelope	U-value roof	[W/m²K]	1.50	0.16
	U-value façade	[W/m²K]	1.50	0.20
	U-value cellar-ceiling	[W/m²K]	1.20	0.28
Windows	U-value	[W/m²K]	3.50	1.30
	g-value	[ ]	0.76	0.60
Energy supply (gas)	Annual efficiency	[η %]	78	97

The retrofit packages detailed in Table 32 lead to the results given in Table 33

Table 33: *Economic assessment of retrofit actions according to an “advanced standard”, moderate zone*

Investment and Results		Terraced House	Multi-family house
Total investment	[€/m²]	224	143
Energy related investment	[€/m²]	103	63
energy-savings	[kWh/m²a]	257	150
Mitigation costs (independent)	[€/t]	6	22
Mitigation costs (coupled)	[€/t]	-140	-136
Cost saved energy (independent)	[cent/kWh]	0.1	0.4
Cost saved energy (coupled)	[cent/kWh]	-3.8	-2.7
Amortisation (independent)	[a]	17	18
Amortisation (coupled)	[a]	7	8

Comparing the advanced retrofit standard with the expert forecast for EPB-standards confirms the conclusion of the assessment of the individual measures: i.e. that the investment costs stay the same or are even slightly reduced, whereas additional energy-savings of approx. 10% can be realised.

4.4 RETROFIT PACKAGES - WARM ZONE

The retrofit package for the warm zone consists of an improvement of the thermal resistance of the building envelope and an improvement of the heating system by installing a condensing boiler, as shown in Table 34. It should be remembered that the cooling load on the building is not taken into account.

Table 34: *Details of retrofit actions (expert forecast EPB, warm zone)*

Warm zone			Before retrofit	After optimised retrofit
Building envelope	U-value roof	[W/m²K]	3.40	0.43
	U-value façade	[W/m²K]	2.60	0.48
	U-value cellar-ceiling	[W/m²K]	3.40	0.48
Windows	U-value	[W/m²K]	4.20	2.71
	g-value	[ ]	0.86	0.63
Energy supply (gas)	Annual efficiency	[η %]	78	97

The retrofit packages shown in Table 34 lead to the results displayed in Table 35.

Table 35: *Economic assessment of retrofit actions (expert forecast EPB, warm zone)*

Investment and Results		Terraced house	Multi-family house
Total investment	[€/m²]	143	87
Energy related investment	[€/m²]	63	37
Energy-savings	[kWh/m²a]	201	150
Mitigation costs (independent)	[€/t]	-101	-85
Mitigation costs (coupled)	[€/t]	-190	185
Cost saved energy (independent)	[cent/kWh]	-2.0	-1.7
Cost saved energy (coupled)	[cent/kWh]	-3.8	-3.7
Amortisation (independent)	[a]	10	11
Amortisation (coupled)	[a]	4	5

In Southern European countries the installation of the retrofit package to achieve the standards of the expert forecast for the EPB Directive is cost-effective either when coupled with maintenance or carried out as an independent measure. This is the result of a usually poor insulation standard before retrofit and the lower material and labour prices in Southern Europe.

Whether this approach is still cost-effective when applied to buildings which already have an improved energy performance, is considered in Tables 36 and 37. Here the details and results of retrofitting the standard house type of the previous report [Ecofys 2004] are given for buildings in the warm climatic zone built between 1975 and 1990.

Table 36: *Characteristics of retrofit actions (expert forecast EPB, warm zone)*

Warm zone			Before retrofit	After optimised retrofit
Building envelope	U-value roof	[W/m²K]	0.80	0.43
	U-value façade	[W/m²K]	1.20	0.48
	U-value cellar-ceiling	[W/m²K]	0.80	0.48
Windows	U-value	[W/m²K]	4.20	2.71
	g-value	[ ]	0.86	0.63
Energy supply (gas)	Annual efficiency	[η %]	78	97

The retrofit packages described in Table 36 produce the results shown in Table 37.

Table 37: *Economic assessment of retrofit actions (expert forecast EPB, warm zone)*

Investment and Results		Terraced House	Multi-family house
Total investment	[€/m²]	143	87
Energy related investment	[€/m²]	57	34
Energy-savings	[kWh/m²a]	75	44
Mitigation costs (independent)	[€/t]	325	330
Mitigation costs (coupled)	[€/t]	-32	-31
Cost saved energy (independent)	[cent/kWh]	6.6	6.6
Cost saved energy (coupled)	[cent/kWh]	-0.7	-0.6
Amortisation (independent)	[a]	37	39
Amortisation (coupled)	[a]	15	15

For buildings in Southern Europe that have already improved their energy-efficiency it is concluded that the measures are still a financial benefit for the investor if coupled to maintenance measures which are required in any case.

Overall, the evaluation of retrofit packages confirms that in economic terms there is a big opportunity in coupling energy-efficiency measures with general maintenance and retrofit measures. Due to the comparatively long time-span of normal retrofit cycles of about 30-50 years, the opportunities of combining regular retrofits with energy-saving measures should be taken up.

5] APPLICATION OF ENERGY RETROFIT PACKAGES TO THE EUROPEAN BUILDING STOCK

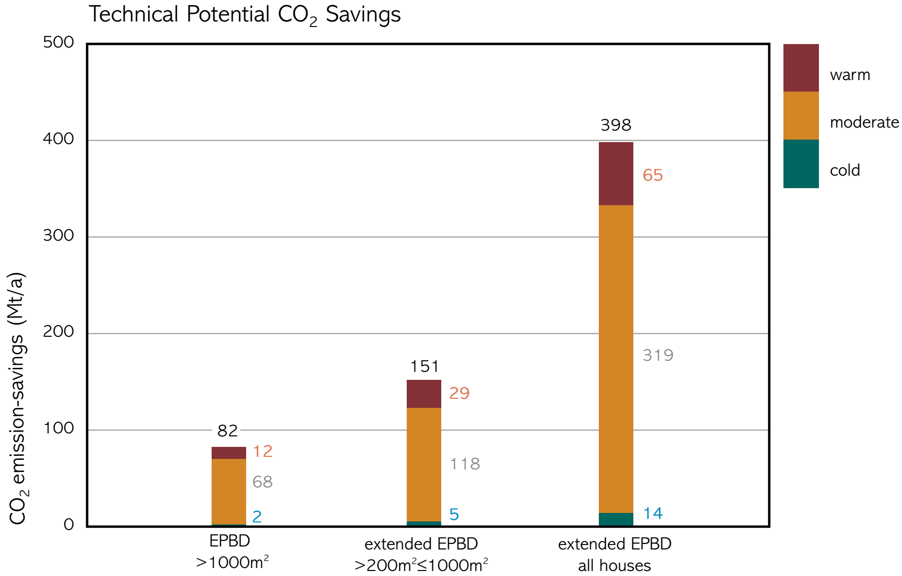
In the previous Ecofys report "Mitigation of CO_2 Emissions from the Building Stock" [Ecofys 2004] the effect of the EPB Directive and its possible extensions on the emissions associated with the heating energy consumption of the total EU-15 building stock was analysed. The ECOFYS energy model of the European building stock BEAM (**B**uilt **E**nvironment **A**nalysis **M**odel) was used for the analysis. (A detailed description of the model is annexed in the above-mentioned report.) The analysis was conducted making the theoretical assumption that all buildings covered by the Directive are retrofitted at once according to the insulation standard coming into force after the implementation of the Directive. On the other hand different scenarios were developed to determine the effect of energy-saving measures over a time span ranging from 2002 to 2015.

In the following section the investments required and their cost-effectiveness are analysed to assess the financial impact of insulation and energy-efficiency measures for the EU-15 building stock. The analysis applies the previously investigated energy retrofit packages to the house types of the BEAM tool. This is done to observe the technical potentials and the influences of phased implementation described in the scenarios.

5.1 TECHNICAL POTENTIAL IN THE EU BUILDING STOCK

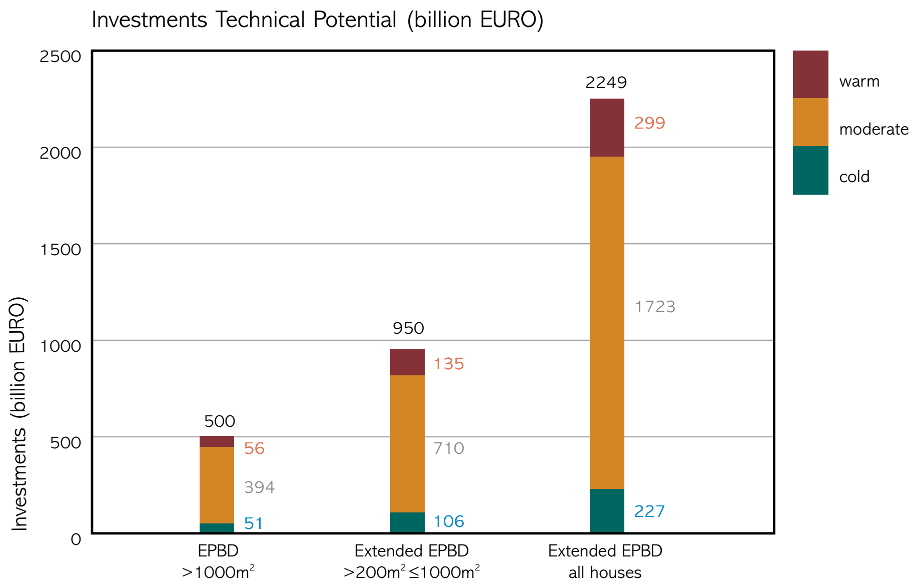
The analysis showed that the overall CO_2 emission savings would add up to 82 Mt/a, if all retrofit measures in the scope of the Directive were realised immediately for the complete residential and non-residential EU-15 building stock (see Figure 15). An additional savings potential of 69 Mt/a would be created if the scope of the Directive was extended to cover retrofit measures in multi-family apartment dwellings (200-1000m²) and non-residential buildings smaller than 1000m² used floor space. If the large group of single-family dwellings was included this would lead to a potential for further CO_2 emission reductions of 316 Mt/a. Note that the scenarios assume insulation standards which would be in force after the implementation of the Directive according to expert forecast. The potential would increase further if better standards were applied.

Figure 15: *Technical potential of the Directive and possible extensions (EU-15)*



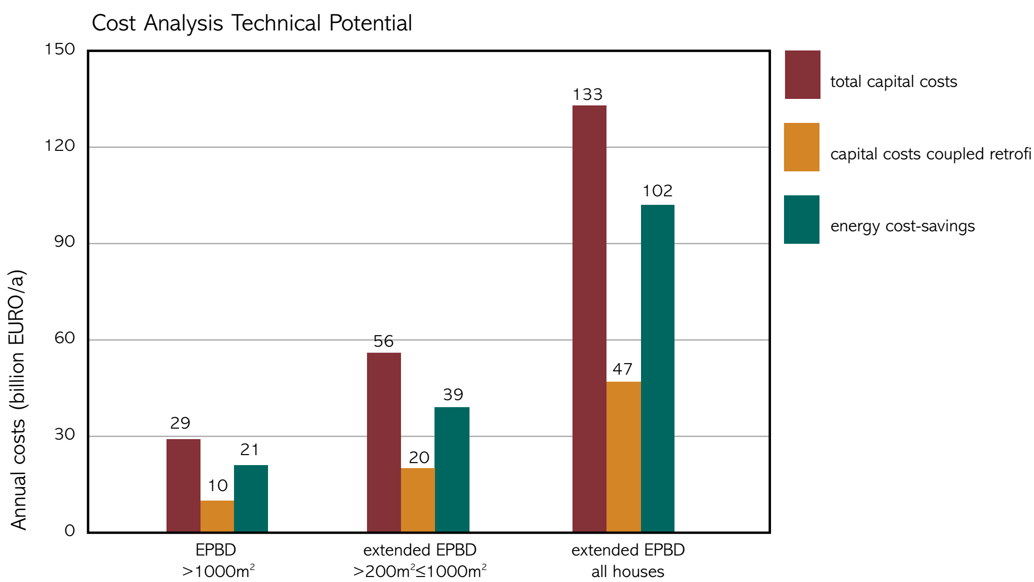
A total investment of approximately 500 billion EURO would be necessary if all retrofit measures in the scope of the Directive were implemented immediately in the complete residential and non-residential building stock (see Figure 16). An additional investment of 450 billion EURO would be necessary to implement retrofit measures in multi-family apartment dwellings (200-1000m²) and non-residential buildings of less than 1000m² useful floor space. The inclusion of all house types would require an additional investment of about 1750 billion EURO compared with the expenditure to meet the Directive.

Figure 16: *Required investments to mobilise the technical potential (EU-15)*



In Figure 17 the investment costs are converted into annual capital costs over the lifetime of the energy-efficiency measures and compared with the annual energy cost-savings. This shows that the technical potential cannot be realized in a cost-effective way because the annual capital costs exceed the yearly energy cost-savings by 30% - 44% depending on the scope of the Directive and its possible extensions.

Figure 17: *Annual capital costs vs. energy costs savings (EU-15)*



In addition to the total annual capital costs the energy-related annual capital costs are investigated, assuming that the energy-saving measures can be implemented as part of the conventional renovation necessary to avoid deterioration. When taking into account only this energy related share of the total investments it can be seen that the related energy cost-savings exceed the annual capital costs of a coupled renovation.

This leads to the conclusion that the large CO_2 saving potential of the building stock can be tapped in a cost-effective way if energy-saving measures were combined with the standard renovation cycle.

On the other hand it proves that each renovation without energy-saving measures is a missed chance to reduce the CO_2 emissions of the building stock and does not recur before the next renovation cycle 30-50 years later.

These facts are considered in the following scenarios, which were developed to determine the effect of different measures over the time span betwen 2002 and 2015. Note that the analysis always combines energy-saving measures with the regular renovation cycle.

5.2 PHASED DEVELOPMENT OF THE EU BUILDING STOCK

In addition to the technical potential, scenarios were developed to analyse the effect of phased application of the Directive and its possible extensions. The scenarios take into account the fact that the existing building stock will not be retrofitted all at once. Also, they consider that the building stock is not only affected by retrofitting but also by demolition and by new construction alternatives.

In the following section the scenario for the implementation of the Directive (EPBD) and two extensions (extended EPBD>200m^2, extended EPBD all house types) is compared with a business-as-usual scenario (BAU) which represents retrofit measures directed at energy-efficiency in accordance with common practice. A detailed description of the scenarios can be found in the above-mentioned Ecofys report [Ecofys 2004].

Calculations demonstrate that regulations introduced following the EPB Directive result in a decrease in CO_2 emissions of 34 Mt/a by the year 2010 compared to the BAU scenario. Extending the scope of the EPB Directive to all residential buildings (including single and multi-family apartment dwellings) the CO_2 emission savings potential over the ‘business-as-usual’ scenario could be doubled to 70 Mt/a by the year 2010. This creates an additional savings potential of 36 Mt/a compared to the Directive.

***Figure 18:** Temporal evolution of CO_2 emissions of the EU-15 Building Stock*

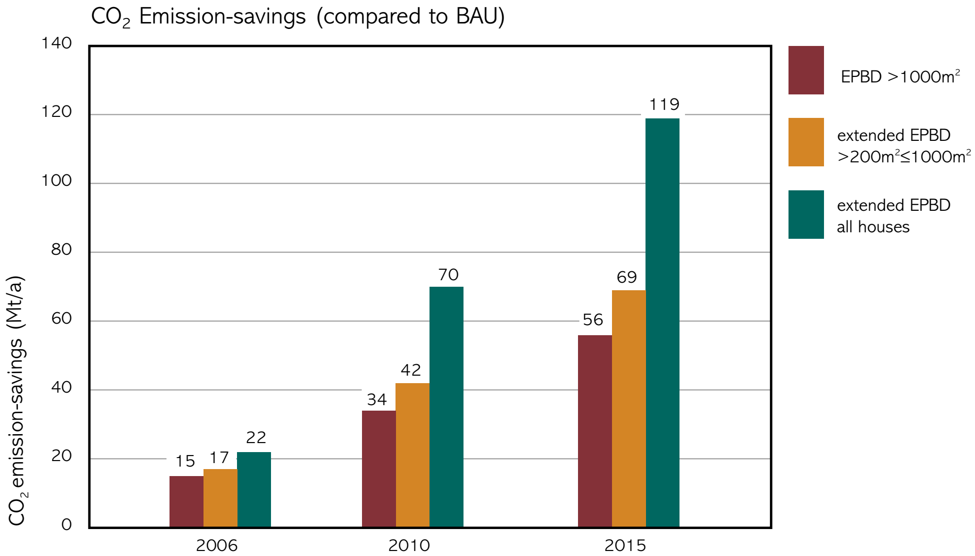


Figure 19 displays the investments required to implement the different scenarios. In order to reach the targets of the EPB Directive scenario an annual investment of nearly 10 billion EURO additional to the BAU scenario is needed beginning in the year 2006. Extension of the scope of the EPB Directive to all buildings requires an additional annual investment amounting to about 25 billion EURO. The minor decrease in investments in 2015 compared to 2010 is caused by the fact that the energy standard of the buildings which are to be renovated now are slightly worse than the buildings which will have to be renovated in 2015.

Relating these values to the general annual turnover of the building industry of 910 billion EURO [FIEC 04], the annual turnover is increased by the EPBD by 1%. Extending the EPBD to buildings greater than $200m^2$, the turnover increases by 1.5%; an extension to all buildings would result in an increase of 3%. This demonstrates that the great potential in the building stock can be realized without radical changes to the construction industry but with an increase in turnover.

Figure 20 illustrates the conversion of the investments required to meet the EPB Directive to annual capital costs over the lifetime of the energy-efficiency measures. It can be seen that the annual capital costs for the EPBD scenario increase from 1.7 billion EURO in the year 2006 to 6.6 billion EURO in the year 2015 and for the extended directive to all house type from 2.6 to 15 billion EURO for the same years. This increase is caused by the fact that the investments of one year result in annual costs over the next 30 years. That means that in the second year with constant investments the annual capital costs are doubled and so forth.

In the same way as annual capital costs increase the energy costs decrease in the same years (see Figure 21). In the EPBD scenario the energy costs savings rise from 3.3 billion EURO in the year 2006 to 13.5 billion EURO. Extending the scope of the Directive to all house types the energy costs savings amount to 4.8 billion EURO and 29.0 billion EURO in 2006 and 2015 respectively. The primary reason for the saving is the rising number of well-insulated houses. Of minor influence are energy prices which are assumed to rise at 1.5% per year.

The comparison of Figure 21 and Figure 19 shows that under all scenarios the energy costs saved exceed the new investment costs. This indicates that all the scenarios can be implemented in a cost-effective way because the yearly benefits rise above yearly expenses before the end of the life of the first implemented measure.

The profitability of the scenarios is illustrated in Figure 22 which shows the difference between the annual capital costs and yearly energy cost-savings. Depending on the scenario the yearly profit rises from 1.6 billion EURO in 2006 to 6.6 billion EURO (EPBD) or 2.2 billion EURO in 2006 to 13.7 billion EURO (extended EPBD to all houses).

Due to the cost-effectiveness of the measures all scenarios lead to negative CO_2-mitigation costs. Comparing this result with the described threshold for acceptable mitigation costs of 20€2000/tCO_2e (see chapter 2.4) we conclude that extending the EPBD to all house types would result in lower mitigation costs and thus represents a more attractive option from the economic perspective than more cost-intensive mitigation options. The large CO_2 savings potential of the building stock can be tapped in a cost-effective way.

Figure 19: *Investments (EU-15)*

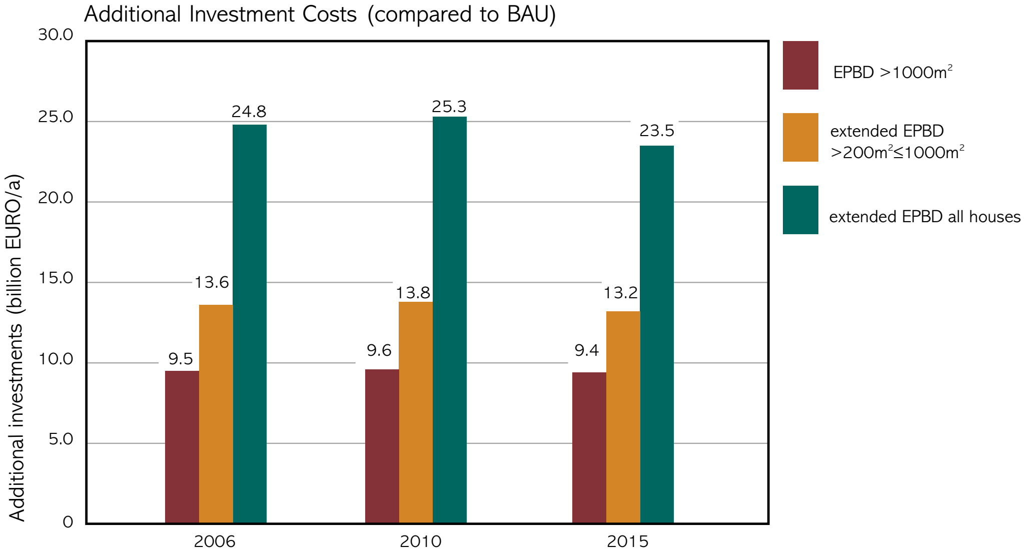


Figure 20: *Annual capital costs (EU-15)*

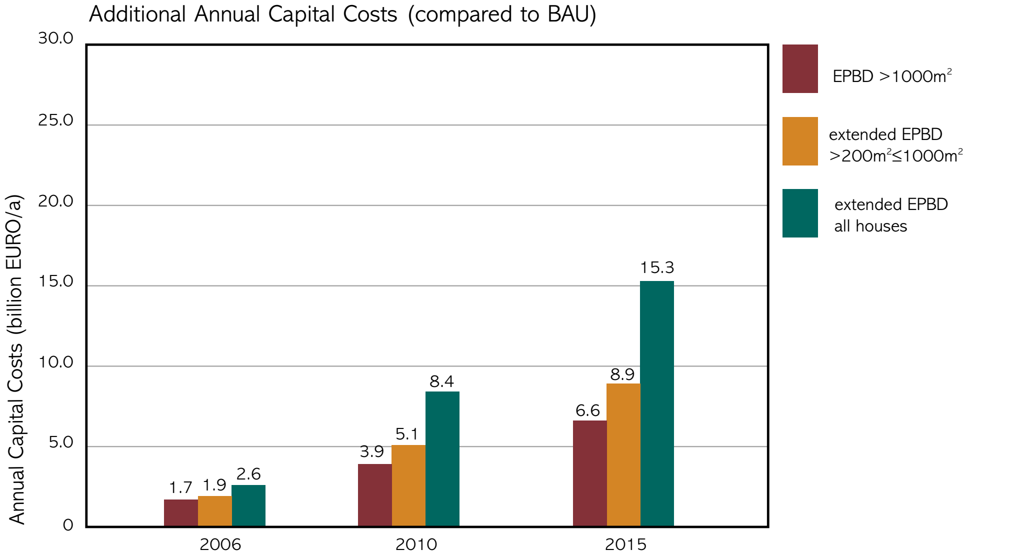


Figure 21: *Energy cost-savings (EU-15)*

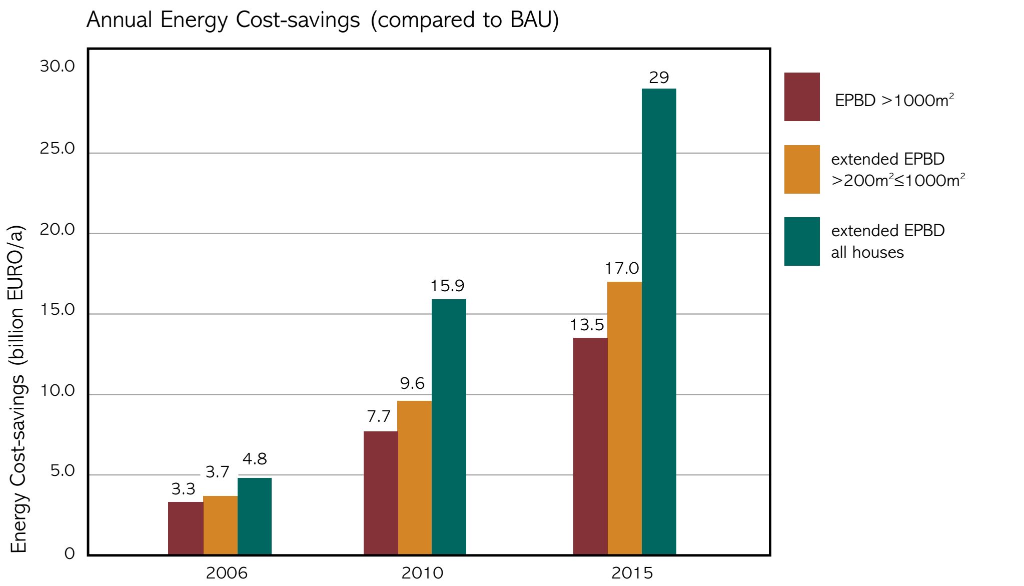
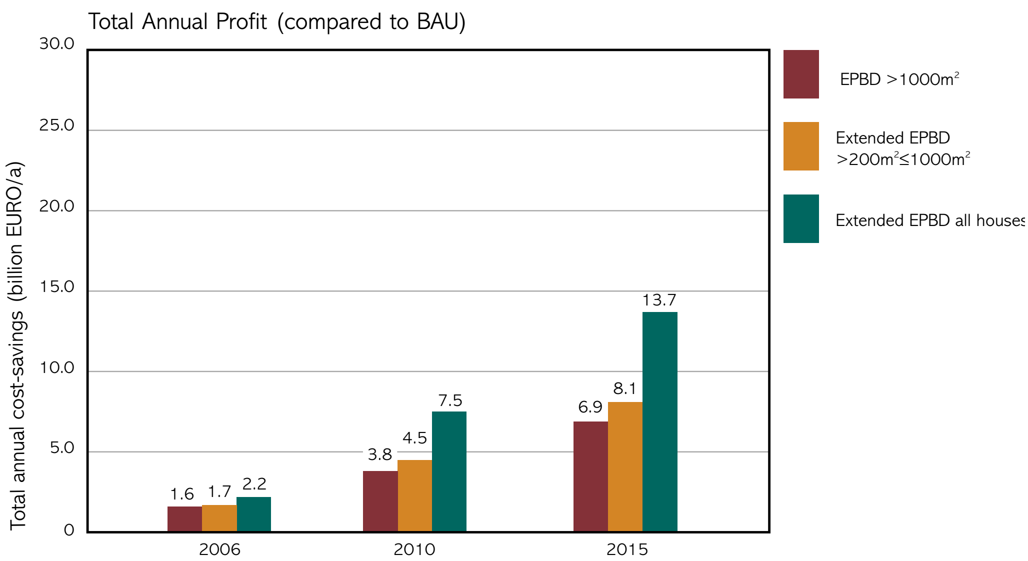


Figure 22: *Total cost-savings (EU-15)*



5.3 ADDITIONAL BENEFITS

Apart from the CO_2 savings potential and the mitigation costs other effects have to be considered in the discussion of the economic impacts of implementing greenhouse gas reduction measures e.g. external costs due to damage expected as consequence of further warming of the earths atmosphere. Other ancillary benefits of climate policies must also be considered e.g. improved urban air quality. Furthermore, increased investment can be expected to exert a positive influence on job markets in EU Member States e.g. in the building sector.

5.3.1 Avoided Damage Costs

Great uncertainties remain in estimating the external damage costs of the greenhouse gas effect. These include uncertainties in understanding the climate mechanisms in the earth's atmosphere as well as uncertainties in evaluating the socio-economic changes resulting from climate change. Physical impacts of climate change have been estimated, including: sea level rise, extreme weather events, human health effects, agriculture, water resources and ecosystems including potential migration processes. A sharp distinction between assessing the damages and allocating clear damage costs is often not possible since the impacts are interlinked with each other.

Table 38 below provides an indicative overview of marginal external damage costs as a result of carbon dioxide emissions. The magnitude of results spans from 0.1 to 16.4 €/tCO_2 and are based on calculations run with the model FUND 2.0 with a time horizon until up to 2100.

Table 38: *Summary of recommended marginal external damage costs calculated for ExternE [a] (World Averages) [Friedrich 01]*

Avoided damage costs	Minimum	Low[b]	Central estimate	High[b]	Maximum
(€$_{2000}$/tCO_2)	0.1	1.4	2.4	4.1	16

[a] emissions in period 2000-2009. Costs are discounted to year 2000

[b] lower and higher value correspond to the 67% confidence interval

Leading experts on valuing damage costs e.g. Tol, Downing and Frankenhauser conclude [Tol 00]: "...the marginal costs of carbon dioxide emissions are uncertain and sensitive to assumptions that partially reflect ethical and methodological positions, but are unlikely to exceed 50$ per tonne of carbon." 50$/t C would correspond to 13.6$/$tCO_2$.

5.3.2 energy-efficiency & Job Creation

Effects on employment and job markets as a result of the implementation of the EU Directive on the energy performance of buildings will depend upon complex macroeconomic feedback mechanisms, as is the case with any other policy implementation. Generally the employment effects from additional investments have to be compared to a situation involving an alternative usage of the capital involved e.g. for consumption in consumer goods, additional savings or payment of corporate dividends. The characterisation of these indirect effects involves a large number of uncertainties which can lead to vastly different conclusions.

The EU EPB Directive is expected to have several effects on employment. These include effects on the volume of construction works, effects on the volume of jobs to design and manufacture heating, cooling and ventilation installations, effects on the volume of jobs for the maintenance of technical equipment such as boilers and air conditioning, and effects on jobs due to the implementation and operation of centralised billing systems.

To date only a limited number of studies have addressed the implication of CO_2 measures on job creation.

The Centre for Energy Conservation and Environmental Technology at Delft in the Netherlands estimated in 1995 an increase in jobs by a net total of 71,000 for the Netherlands [Davidson 95]. This would be achieved by investment in energy-efficiency improvement measures, lower turnover in the energy sector, re-investment of saved money and the promotion of wind energy. The study investigated the potential employment effects of achieving the 'Toronto target' for the Netherlands, that is a 20% cut in Dutch carbon-dioxide emissions from fossil fuel burning by 2005 based on 1988 levels (180 Mton). The total potential net employment effect was recorded as an increase of approximately 1% of the total employment in the Netherlands.

A recent study, conducted by the Jülich Research Centre (2004), assessed "Environmental protection and job creation by activities of chimney sweeps in Germany" [Kleemann 04]. Employment effects were estimated for servicing activities, replacement of heating appliances and for energy consulting services. In total 45,700 jobs could be created in Germany as a result of these activities whereas the majority (almost 90%) of the jobs would result from replacement activities.

Another study was conducted on "Major Energy Saving, Environmental and Employment Benefits by Double-Glazing and Advanced Double-Glazing Technologies" [DG XVII 95], and was carried out in 1995 for EC DG XVII (Energy, Thermie Programme). The employment benefits as a result of energy and CO_2 savings obtained by installing high-performance glazing in existing EU dwellings were estimated. It was assumed that a ten-year upgrade program was adopted throughout the European Union in order to accelerate the conversion of existing windows. The study concluded that there would be an opportunity to create some 110,000 new jobs for the entire ten-year period.

For a detailed analysis of the employment impacts resulting from the EPB Directive an in-depth calculation would need to be undertaken with a complex macroeconomic modelling tool in order to understand feedback mechanisms. However, in this report, based on the scenarios presented it was recommended that energy optimised renovation packages should be coupled with the renovation cycle. Thereby the energy-saving measures are integrated cost-effectively in the renovation process and several measures are limited to the use of energy efficient components, e.g. thicker insulation, better windows, high efficiency boilers. Therefore the additional labour required on the construction site is limited. Other measures like cavity insulation will have a higher influence on the labour requirement because this is an additional measure.

As a first estimate of direct employment effects the additional investments can be compared with the turnover and employment of the construction industry, where 11,7 million operatives generate a total turnover of 910 billion EURO/a [FIEC 2004]. This corresponds to a turnover of 78,000 EURO/a per employee. It can be assumed that the share of material costs in the scenarios discussed above is a factor of 2 – 5 higher than conventional construction activities. Thus, an additional 150,000 - 400,000 EURO invested into energy-savings packages would generate one new position. The most ambitious packages with additional investments of 25 billion EURO annually would therefore correspond to roughly 50,000 - 150,000 additional new jobs in the construction and installation industries. This does not take into account the influence on other industries (e.g. energy or manufacturing industry) and is obviously a very rough estimate of direct effects, but certainly warrants further analysis. Nevertheless it can be concluded that moderate positive employment effects in the range of around 10,000 to 100,000 jobs across Europe would result from the implementation of the packages discussed above.

6] CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1 ADDITIONAL BENEFITS OF CLIMATE PROTECTION

The large gap between EU targets under the Kyoto protocol and current greenhouse gas emission levels in Europe together with the necessities of long-term climate protection require substantial further emission reductions. These reductions should be achieved without loss of competitiveness or jobs. Instead it is highly desirable that clear additional benefits are realised hand in hand with greenhouse gas emission reductions such as the improvement of urban air quality, increased security of the energy supply and the creation of sustainable new jobs.

6.2 EXTENDING THE EPB DIRECTIVE

This study has identified a portfolio of cost-effective energy conservation measures and retrofit packages which might be applied to the European building stock. For respective retrofit packages the economic optimum as a function of insulation thickness has been determined. It was observed that the insulation thickness that can be expected as the result of the implementation of the EPBD in warm and moderate climates is in the on the low side of insulation levels corresponding to the economic optimum. Increased levels of insulation would lead to further savings without significant negative financial impact.

Most of the investigated insulation measures and packages are cost-effective. Consequently, the results confirm the principles of Trias Energetica, which postulates that energy-saving measures should be implemented to reduce demand before the remaining energy demand is generated by renewable technologies, where feasible, or energy efficient technologies. These principles could be included in the implementation of the EPB Directive in national legislation by imposing requirements on overall energy performance and also by mandating minimum insulation levels.

Moreover it became evident that the measures are similar for all building types. Since energy conservation measures make economic sense in all buildings types and not only in buildings greater than 1000m^2, it would be sensible to extend the EPBD and create a contribution towards closing in on the EU CO_2 emission target.

6.3 MAIN BARRIERS

Apart from governmental regulations and financial issues, other factors influence decision-making in relation to the implementation of energy-efficiency measures:

- Increase of the property value by conservation or appreciation of architectural values
- Improvement of the social environment
- Improvement in comfort through better room climate
- Aesthetic values
- Financing issues
- Habitual behavioural patterns

One of the main barriers for the implementation of energy-saving measures, especially in rented apartments, is the divergence in interests of the tenant and the owner/investor: Whereas the ownesr of the houses (e.g. housing associations) are the ones who invest in the energy-saving measures it is the tenants who benefit from the reduction of energy costs. Often the opportunities to increase the rent are (legally) limited or the return on investment is extended over a long period of time.
There is another impediment common among privately owned small residential homes: At the time at which maintenance or retrofit measures become necessary, a lack of funds may shift the decision towards smaller investments and less energy efficient solutions despite the better economic alternatives available for greater investment

6.4 REMOVING BARRIERS

In order to overcome these obstacles, the EU, national governments, and banks can play an active role in providing a supportive framework for the implementation of the new EU Directive on the energy performance of buildings. These organisations may facilitate the access to direct and indirect financial support and could provide incentives for investors in refurbishment projects in EU Member States. The following options could be considered for further discussion at policy level.

- **Establishing revolving funds for refurbishment projects at regional level:** Revolving funds can be developed and administered by public institutions as a financing mechanism to support the investment in energy-efficiency measures in the building sector. A reserve of money could be made accessible to registered organizations or individuals. Over a given period of time the debtor is expected to repay the original sum, which will replenish the fund and allow others to benefit from loans. The financial savings achieved by energy-efficiency projects, that can easily be determined, are funnelled back into the capital fund thus creating an ongoing revolving capital fund. Each year these savings are reinvested into the fund until the capital investment is paid off. Revolving funds were implemented and tested in various countries such as the UK and turned out to be a suitable means for pursuing longer-term targets.

- **Providing incentives through reduced interest rates on loans:** A targeted subsidy policy could be introduced to help financing of improved energy-efficiency measures in the building sector. Reduced interest rates on loans issued by banks would be another option. These policies have to be consistent in order to achieve a good result, which means that the earmarked subsidy amount and the demand for e.g. improved insulation technologies must match. However, to tie up these types of subsidies with loan arrangements runs the risk that subsidies are hard to acquire if the customer wanted to install technology on their own. There should be a clear indication of which measures are subsidized; though receipt of subsidies should not be dependent upon the equipment supplier an investor purchases technology from. A problem area with such schemes is that subsidies provided for mature and thus commercially available technologies may result in increasing prices and degrade the quality of services.

- **Lowering the Value Added Tax:** As another option the Value Added Tax (VAT) could be lowered in EU Member States for any product type that contributes to decreasing energy consumption in buildings. Typically, this would apply for insulation material, improved windows or state-of-the-art heating technology to be implemented during refurbishment measures. Lowering VAT would accelerate and support sales mechanisms of these products and could lead to stimulating the construction supply markets in general.

- **The right legal framework for retrofitting:** Additional financial incentives might be given to investors in energy-saving measures for the existing building stock. In some EU countries investors are allowed to increase rental fees after a refurbishment measure to a maximum of two times the saved energy costs provided the measures improved the energy-efficiency of a building. With or without involvement of the EU a similar legal framework could be expanded to cover other EU Member States.

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8] ANNEX 1 - MODEL DESCRIPTION

For the research project "The contribution of Mineral Wool and other Thermal Insulation Materials to Energy-saving and Climate Protection in Europe" [Ecofys 2002], Ecofys has developed a model displaying the actual condition and future developments in the European building stock to analyze potential energy-saving through thermal insulation. Statements concerning energy-savings through thermal insulation are based on a calculation model structuring the building stock in a simplified manner. This has to be taken into account when evaluating the accuracy of the results. However, the results provide safe indicators of the probable size of energy-saving potentials.
The investigation of the questions, which were raised in connection with the EU-directive, requires certain modifications and additions to the Ecofys model (e.g. the implementation of additional classes of smaller buildings).

> Building types

For the modelling of the European building stock 5 standard house-types were taken into account:

- Model house 1: Two-storey terrace-end-house (120 m^2)
- Model house 2: small apartment house (less than 1000m^2)
- Model house 3: large apartment house (larger than 1000m^2)
- Small office building (less than 1000m^2)
- Large office building (larger than 1000m^2)

> Climatic zones

Different climatic conditions in Europe have been summed up in three climatic zones. The Northern cool climatic zone comprises the following countries: Finland and Sweden wheras Austria, Belgium, Denmark, France, Germany, Great Britain, Ireland, Luxembourg and the Netherlands belong to the moderate central climatic zone. The Southern warm zone includes Greece, Italy, Portugal and Spain.
According to the STOA report [STOA 1998] the following heating degree-days were assumed for the different climatic zones.

Table 39: *heating degree days*

	Heating degree days [Kd/a]
Warm climatic zone	1800
Moderate climatic zone	3000
Cold climatic zone	4500

> Building age groups

The building stock has been subdivided into three building age groups, which differ substantially due to the respective valid national or regional regulations and the insulation standard connected to them.

- Buildings erected before 1975 (subdivided into buildings already energetically redeveloped and buildings in their initial condition)
- Buildings erected between 1975 and 1990
- Buildings erected after 1990

> Characterization of the European building stock[1]

***Table 40:** characterisation of the European building stock*

	Building age	Total	Single family house	Apartment house <1000m²	Apartment house >1000m²	Small non-residential buildings <1000m²	Non-residential buildings >1000m²
	Year	[Million m²]	[Million m²]	[Million m²]	[Million m²]	[Million m²]	[Million m²]
Cold climatic zone	< 1975	534	220	109	59	55	92
	1975-1990	154	63	31	17	16	27
	1991-2002	120	31	26	14	18	30
Moderate climatic zone	< 1975	9,145	4,607	1,242	669	780	1,848
	1975-1990	2,551	1,290	348	187	216	511
	1991-2002	1,708	670	181	97	226	535
Warm climatic zone	< 1975	3,116	1,197	769	414	319	416
	1975-1990	1,945	748	480	259	199	259
	1991-2002	1,175	399	256	138	166	216

> U-values of the building types

According to climatic zone and building age group, different insulation standards and their respective U-values have been applied:

***Table 41:** U-values for climatic zones and building ages*

U-values [W/m²K]	Built before 1975 Not retrofit.	Built before 1975 Already retrofit.	Built from 1975 until 1990	Built from 1991 until - 02	New building 2003-2006[2]	Retrofit 2003-2006	New building after 2006	Retrofit after 2006
Cold climatic zone								
Roof	0.50	0.20	0.20	0.15	0.15	0.15	0.13	0.13
Facade	0.50	0.30	0.30	0.20	0.18	0.18	0.17	0.17
Floor	0.50	0.20	0.20	0.18	0.18	0.18	0.17	0.17
Windows	3.00	1.60	2.00	1.60	1.42	1.42	1.33	1.33
Moderate climatic zone								
Roof	1.50	0.50	0.50	0.40	0.25	0.25	0.23	0.23
Facade	1.50	1.00	1.00	0.50	0.41	0.41	0.38	0.38
Floor	1.20	0.80	0.80	0.50	0.44	0.44	0.41	0.41
Windows	3.50	2.00	3.50	2.00	1.84	1.84	1.68	1.68
Moderate climatic zone								
Roof	3.40	1.00	0.80	0.50	0.50	0.50	0.43	0.43
Facade	2.60	1.40	1.20	0.60	0.60	0.60	0.48	0.48
Floor	3.40	1.00	0.80	0.55	0.55	0.55	0.48	0.48
Windows	4.20	3.50	4.20	3.50	3.04	3.04	2.71	2.71

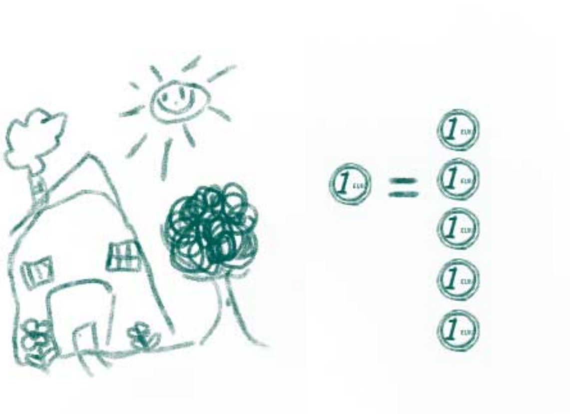
[1] Main source for residential sector: [Fin 01]; main source for non-residential buildings: [Eurotat 01, 02]

[2] The European Directive 2002/91/EC requires implementation in the legislation of the Member States by 4 January 2006

It should be noted that the applied values are only roughly established and some of them had to be estimated despite extensive data investigation. For an exact determination of saving potentials through thermal insulation a detailed building typology of Europe would be necessary.

Table 42: *Characteristics of the standard house-types*

	Unit	Single-family house	Apartment / House >1000m²
Number of dwelling	[ ]	1	16
Living area	[m²]	120	1,637
External volume	[m³]	421	5,374
Form factor		0.64	0.38
Total surfaces		268	2,016
Ground	[m²]	70	437
External walls	[m²]	108	919
Roof	[m²]	70	437
Windows	[m²]	20	224



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