U-VALUES

FOR BETTER ENERGY PERFORMANCE OF BUILDINGS

Report established by ECOFYS for EURIMA

Thomas Boermans
Carsten Petersdorff
(Ecofys Germany)

supported by international Ecofys staff
Erwin Mikkers (Ecofys NL)
Ronald Voskens (Ecofys Spain)
Andy Horsley (Ecofys UK)
Michal Siembab (Ecofys Poland)
Cinzia Maga (Ecofys Italy)

PEPLDE061916

ECO**FYS** GmbH, Eupener Straße 59, 50933 Cologne, Germany, Tel. +49 221 510907-0

U-values
For Better Energy Performance Of Buildings

Report established by ECO**FYS** for EURIMA

FOREWORD

At the Gleneagles Summit in July 2005, leaders of the G8 addressed the serious and long-term challenges of secure and clean energy, climate change and sustainable development. Agreeing to act with resolve and urgency, they adopted a Plan of Action and launched a dialogue with other significant energy users. The G8 leaders asked the International Energy Agency (IEA) to come up with recommendations on action and to be a major partner in the dialogue.

The IEA took policy recommendations to the G8 summits in St. Petersburg in June 2006 and in Heiligendamm in June 2007 and further recommendations will be taken to future G8 summits.

Buildings comprise the largest end use of energy; nearly 40 per cent of the world's end energy use is spent on buildings, including lighting, installed appliances and equipment. Compelling and cost effective opportunities to reduce energy consumption in buildings exist both in IEA member countries and in developing countries.

A policy to reduce energy consumption and greenhouse gas emissions and to ensure sustainable development has to include measures to reduce the end use of energy in buildings. Consequently recommendations on policies for buildings are an important component of the IEA package of recommendations for the G8.

Furthermore, the Governing Board of the IEA endorsed five specific recommendations for policies on energy efficiency in buildings in March 2007 and has strongly encouraged all IEA Member Countries to adopt these policy actions.

Among IEA recommendations, is the enforcement and regular updating of mandatory standards for new buildings (Building Codes). These requirements should be based on least costs over the longer term, to ensure that new buildings are constructed to be energy efficient. The recommendations also propose to set energy requirements for existing buildings to be met by major refurbishment.

This study conducted by Ecofys for EURIMA, is a valuable contribution to the IEA's work on policy recommendations, especially for Building Codes, where the Ecofys Study both supports and extends the IEA recommendations. Showing the gap between existing requirements and the economic optimum over 30 years, the Ecofys study documents that, even in countries with a long tradition of energy requirements, there is still substantial potential to increase efficiency in new buildings without additional costs for end users.

The study also demonstrates that the efficiency requirements when refurbishing existing buildings should be almost the same as for new buildings. Combined with the earlier Ecofys EURIMA studies, this emphasises the potential efficiency gains through refurbishment and other policies to upgrade existing buildings.

The IEA highly welcomes this new study for its contribution to the dialogue among governments, major end energy users and other parties involved in raising the energy efficiency of new and existing buildings worldwide.

William Ramsay
*Deputy Executive Director of IEA**

* INTERNATIONAL ENERGY AGENCY

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The calculations of the overall energy performance of buildings, according to the EPBD has to consider an integrated approach that takes into account all building related energy losses and gains. National or regional energy performance requirements are given in national or regional regulations for fully integrated overall energy performance.

In many countries additional requirements on the maximum energy transmission for single building components expressed in U-values or R-values are given, reflecting the knowledge that it saves costs and improves comfort to ensure first a low energy demand of a building before supplying the remaining energy demand in the most efficient way.

However the national U-value requirements for building components (roof, floor, wall, windows, etc.) often describe minimum requirements that do not reflect the economic optimum or specific environmental targets.

Additionally, the sharp rise in energy prices of the last years and current discussions on climate protection targets have considerably changed the boundary conditions for applying insulation to buildings in Europe. This study therefore aims to contribute to the discussion of policymakers and regulators concerning reconsideration of the national or regional required or recommended U-values for building components.

Regarding the recommendation of U-values, one could choose for a financial point of view and calculate an economic optimum for insulation levels derived from the necessary investment costs and according energy cost savings from reduced heating and cooling energy demand. Another approach is to calculate necessary insulation levels to meet climate protection targets. In this study the results for both approaches have been assessed, leading to the following conclusions:

> The different argumentations, both for cost effectiveness and in the climate protection approach, result in comparable maximum U-values. This means that climate protection and cost efficiency are not contradictory but can be well combined.

> Recommended maximum U-values resulting from the analyses based on cost-efficiency and possible Post-Kyoto targets are in most cases more ambitious than current national standards, offering room for improvement of requirements.

> The study demonstrates that once the cost savings for heating and cooling energy exceed the total investment costs for insulation measures, the optimum U-value (mainly determined by the contribution of insulation) is the same for new and existing buildings, as long as no technical limitations occur. In this sense the recommended U-values apply to new and existing buildings.

> In residential buildings of southern Europe thermal insulation also reduces the energy demand for cooling. Especially roof and wall insulation combined with proper shading and a good ventilation strategy provides very robust and considerable savings. A well balanced package of floor, wall and roof insulation results in a significant and cost-effective reduction in the energy demand for heating and cooling.

2] INTRODUCTION

The European Directive on Energy Performance of Buildings (EPBD), which came into force 16 December 2002 to be implemented in the legislation of Member States in 2006, aims to improve the overall energy efficiency of new buildings and large existing buildings during significant renovation. Because the building sector being responsible for about 40% of Europe's total energy consumption, the EPBD is an important step for the European Union to reach in order that it should achieve the level of saving required by the Kyoto Agreement; the EU is committed to reduce CO_2 emissions by 8 per cent by 2010 relative to the base year of 1990.

The impact of the EPBD has been quantified in earlier Eurima studies[1] for the potential monetary savings, investments and CO_2 savings. All studies were carried out by Ecofys. The basis for the analysis is the ECOFYS energy model of the European building stock BEAM (Built Environment Analysis Model).

Questions concerning the EPBD and its implementation were covered in the following Ecofys-reports:

Report	Content
Mitigation of CO_2 Emissions from the Building Stock – Beyond the EU Directive on the Energy Performance of Buildings *Report II, February 2004*	Reduction of CO_2 emissions in the EU15 building stock resulting from current and extended EPBD. Excursus: Effects of insulation on cooling demand.
Cost-Effective Climate Protection in the EU Building Stock *Report III, February 2005*	Economic assessment of CO_2 mitigation measures and retrofit packages in the EU15 countries
Cost-Effective Climate Protection in the Building Stock of the New EU Member States - Beyond the EU Directive on the Energy Performance of Buildings *Reports IV and V, August 2005*	Reduction of CO_2-emissions in the new Eastern European member states (New EU8) resulting from current and extended EPBD including an economic assessment of retrofit measures and packages.
Sensitivity Analysis of cost effective Climate Protection in the EU Building stock *Report VI, June 2006*	Sensitivity analysis of the calculations on cost-efficiency for the EU15 and NEW8 (reports III to V) on basis of 5 energy-price scenarios.

The reports cover the topics of CO_2-emission savings and cost efficiency from energy saving measures in the existing EU15 and the New EU8 countries. The proven cost effectiveness of the investigated retrofit packages confirms the validity of the principles of the Trias Energetica, which postulate that energy-saving measures should be implemented to reduce demand first. The remaining energy demand then should be preferably generated by renewable technologies, or with energy efficient technologies based on fossil fuels.

[1] Eurima Ecofys studies:
see: http://www.eurima.org/document_library/eurima_publications.cfm

The reports conclude that these principles can be implemented by the EPBD, following its transposition in national regulations, by the introduction of minimum insulation levels (or maximum U-values) in addition to the requirements for overall energy performance.

The calculations of the overall energy performance of buildings, according to the EPBD has to consider an integrated approach, that takes into account the calculation rules given in a suite of CEN standards for all building related energy losses and energy gains. National or regional energy performance requirements are given in national or regional regulations for fully integrated overall energy performance.
In many countries additional requirements on the maximum energy transmission for single building components expressed in U-values or R-values are given. However the national U-value requirements for building components (roof, floor, wall, windows, etc.) often describe minimum requirements that do not reflect the economic optimum or specific environmental targets.

The study aims to contribute to the discussion concerning reconsideration of the national or regional required or recommended U-values for building components. Regarding the recommendation of U-values, there are two lines of argument that are reasonable to follow:

1. **Cost effectiveness:** In article 6 'Existing buildings' the EPBD states that when buildings with a total useful floor area over 1 000 m^2 undergo major renovation, their energy performance should be upgraded in order to meet minimum requirements in so far as this is technically, functionally and economically feasible. It is essential to assess which measures are technically, functionally and economically feasible for average local market conditions.

2. **Climate change:** In the Post-Kyoto discussion the EU25 ministers for the environment set the target for the reduction of greenhouse gas emissions as 70-90% by 2050. Taking retrofit cycles of 30-50 years in the building stock into account, each building which undergoes refurbishment in 2010 has to fulfil these targets. To implement the targets on a wide scale in 2010 their feasibility has to be demonstrated now. This raises the question, what does the target of 70-90% reduction actually mean for the maximum energy consumption and the associated minimum insulation standard of retrofitted houses in different European climates?

In order to make recommendations for minimum thermal performance levels for building component in Europe, the following steps have been taken:

> Background work description:
- Development of a European heating and cooling degree days maps for the EU25
- Calculation of insulation impact on cooling energy demand in southern Europe

> Recommendation for U-values (thermal performance levels) based on cost-effectiveness and 2 different price scenarios from the Ecofys-report "Sensitivity analysis of cost effective climate protection in the EU building stock", which refers to:
- WEO reference scenario and
- Peak price scenario

> Minimum requirements calculations on overall energy performance to meet the Post-Kyoto targets and conclusion on according insulation standards.

The detailed approach, giving results and their interpretation is described in the following chapters.

2.1 FRAMEWORK AND BOUNDARIES OF THE STUDY

In many European countries the present required U-values for residential buildings may be considered as minimum performance levels. These are no longer entirely based on changed economic conditions resulting from rising energy prices over the past years but reflect an increasing commitment to reduce CO_2 emissions and avoid climate change. These required U-values are given or derived from a calculation based on the integrated method applied to the whole building energy performance, following the principle of the EPBD (2.1.1).

Taking into account any given energy price, one could define three options for energy performance improvement, see Figure 2.

Option 1: legal requirements (minimum energy performance)
Option 2: economic optimum (best practice range)
Option 3: maximum energy performance (state of the art)

The study aims to make recommendations for U-values for the building components wall, roof and (ground) floor for residential buildings (new and existing) on the level of economic optimum (option 2).

The intended recipients of the study are regulators and policy makers. All analyses are based on parameters applicable in a social context regarding interest rates, taxes and CO_2-mitigation costs. These are applicable in the cost-efficiency analyses on the level of the society, but are not necessarily appropriate for investors and private house owners.

The option chosen for analysis is Option 2. Option 1 fails to provide full environmental benefits and optimum social cost effectiveness. Options 3 while probably not economic optimum is still cost effective and should be delivering even better environmental benefits. But the potential complexity of implementing this latter option has not been investigated in this study (2.1.3). It is thought that this option would require a more regional and detailed analysis, which also would include the principle of the Passive House (2.1.4).

2.1.1 COST EFFECTIVENESS PER COMPONENT

The EPBD requires the integrated calculation of energy demand reducing measures, e.g. (solar-) gains, internal heat production and external energy supply for heating and cooling.

The study does not optimise between the possible energy demand reducing and energy supply measures for the building. For each of the components floor, wall and roof the optimum U-values necessary to reduce the energy demand for heating and cooling has been calculated. No interaction and cross effects have been taken into account.

However, in a separate chapter combinations of insulation measures were defined to assess the influence of insulation on cooling, see chapter 4. Also, results of the study (U-values for all three components) have been integrated, and overall energy performance of a typical building obtained following the principle of the calculation method of the EPBD for four countries: Sweden, Poland, Netherlands and Spain.

2.1.2 ECONOMIC OPTIMUM

For each of these building components U-values are given separately for the particular insulation thickness that provides the (theoretical) maximum profit from capitalised investments and energy cost savings.
The economic optimum from investment costs and energy savings is a theoretical calculated optimum. The optimum is placed in the minimum zone of the total costs curve. That is why in reality the optimum covers a rather wide zone. (see Figure 1 and Figure 2).

Figure 1: Definition of economic optimum

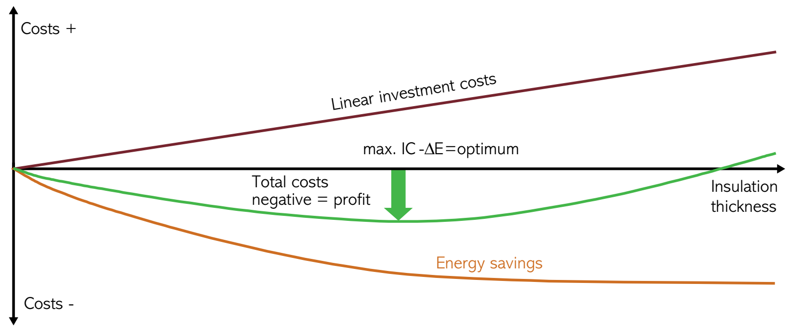
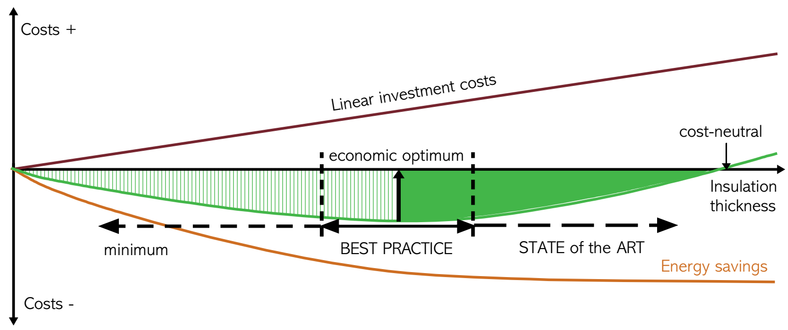


Figure 2: Position of the economic optimum



Both to the left and to the right from the theoretical economic optimum U-values, on the basis of the corresponding optimum are to be considered as profitable investments i.e as long as the total costs from investments and energy costs savings are negative. But even beyond the point of cost neutrality of a single measure a synergetic combination of measures can justify to invest beyond that point if the aggregated costs of the combined measures are negative. This however is not considered in the calculations made in this study.

The study calculates and compares the relative position of the optimum from the existing minimum U-values, either required or recommended at present in the EU countries.
It should be appreciated that other reasons than the economic optimum may apply to the existing given U-values in national and regional regulations or recommendations.

Due to the shape of the cost curves around the optimum (see basic principle in Figure 1 and Figure 2) it is possible to go beyond the calculated optimum with still reasonable cost efficiency, leading to higher energy and CO_2-emissions savings. Taking into account not only cost efficiency but also environmental targets, reduced dependency of energy imports etc., this can be a meaningful option, which is realised already in some of the assessed countries.

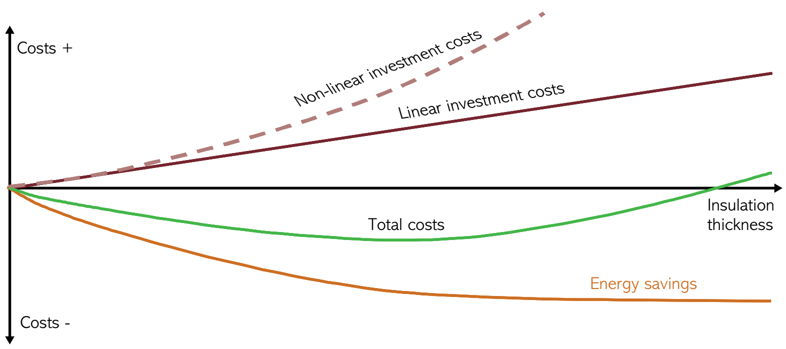
2.1.3 SIMPLE LINEAR INVESTMENT

As mentioned before, the study does not take into account additional investments and/or avoided or lower investments brought about by the need for physical changes to the building resulting from change in insulation thickness nor does it allow lower investments in other energy efficiency measures or in the design concept of the building.

As examples:

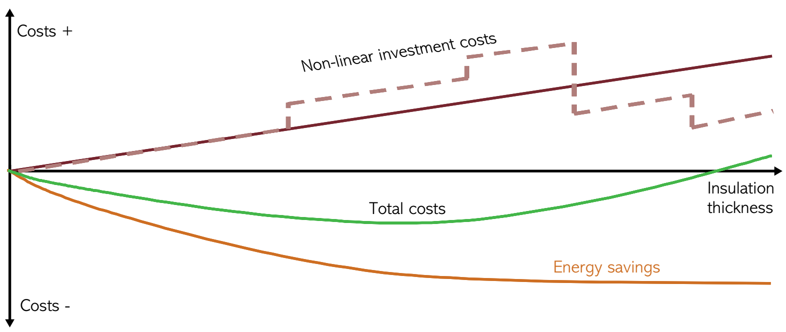
> A continuously increasing investment could be necessary as insulation thickness is increased. This is because increased insulation thickness brings with it the need for:
- Thicker window frames
- Increased cavity width
- Increased width of the wall supporting the foundations
- Different timber beams in the roof construction, etc.

Figure 3: Non-linear investment costs (1)



> A positive effect of the increasing insulation thickness is a lower energy demand which would require a lower capacity from the boiler and the heat transfer system in the building.

Figure 4: Non-linear investment costs (2)



The study does not take into account these positive or negative changes in the investment cost as the insulation thickness for particular component is increased, nor does it take into account the impact of other building components or the consequences from other energy related investments.
The study does assume a simple linear investment, based on the incremental costs per centimetre of insulation thickness based on an average.

2.1.4 THE PASSIVE HOUSE

The study, as mentioned before, does not deal with a complete building evaluation for determination of the most (cost-) effective combination of energy efficiency measures but looks at insulation measures per component assuming traditional heating systems. But when combining different energy efficiency measures in a meaningful way, synergies in terms of energy savings and cost can be achieved as e.g. demonstrated by the Passive House concept.

The Passive House concept is based on the principle that heating and cooling demand is reduced to an absolute minimum. For this the reduction of heating, cooling and ventilation on the related energy demand has an overwhelming priority. The remaining demand is then supplied preferably by a combined ventilation-heating-cooling solution, which is preferably using solar heat, photovoltaic energy, heat pump and/or earth heat and cooling energy. This principle concept does not rely on traditional heating and ventilation systems. The Passive House concept also relies on the principle that thermal bridges have been reduced to absolute minimum by design of the construction (or by renovation).

The Passive House concept economically balances the various available solutions mentioned before. The commonly applied U-values for the Passive Houses are of the order of U=0,10 to 0,05 W/m^{2}K and often incorporate an insulation exceeding 40 to 50 centimetres in thickness.

The study does not deal with Passive House concept, the heating systems and ventilation systems, that have been assumed in the study are traditional systems and there is no whole building evaluation for determination of the most (cost-)effective combination of energy efficiency measures.

2.2 USE OF THE STUDY AND ASSUMPTIONS/RESTRICTIONS OF THE ANALYSES

Summarising with reference to the boundaries and restrictions mentioned under chapter 2.1 the study should be required reading for policy makers and regulators.

It is expected that the study will stimulate a review of national U-value requirements or recommendations with respect to:

- residential buildings: new and existing
- the actual and expected energy price
- the contribution of the national building stock to Post-Kyoto CO2-target

The results are based on:

- the climate data in 100 European cities
- the economic optimum U-value (heat transmission value in W/m^{2}K) in practice representing a certain spread around this theoretical value
- the economic optimum, representing the Best Practice value for a single building component like a wall construction, roof construction or floor construction
- a simplified linearity in the investment costs
- non-specific prices for insulation materials and auxiliary materials
- the average U-values of non-insulated or existing constructions
- energy prices and energy mix per zone(north, central, south, east)
- investment costs of insulation measures per zone (north, central, south, east)
- (social) interest rates of 4% and 6% (west and east respectively)
- residential buildings with traditional heating and ventilation systems (no heat recovery systems, no Passive Houses)

Requirements for better U-values driven by the need for higher thermal values when electric heating is applied are not covered. Also requirements for better U-values driven by other building physical conditions like condensation risks or acoustical requirements are not covered.

3] BACKGROUND

3.1 EUROPEAN HEATING AND COOLING DEGREE DAYS MAPS

3.1.1 DEFINITION HEATING/COOLING DEGREE DAYS

Heating degree days express the severity of the cold over a specific time period taking into consideration outdoor temperature and room temperature. For calculating heating degree days of European cities, weather data where taken from METEONORM and calculated to heating degree days (HDD) using the methodology applied by EUROSTAT, which form a common and comparable basis. External and internal building conditions may require additional energy for cooling and ventilation in order to meet a defined comfort level. This comfort level may be defined in building regulations or be given as user specifications. In order to meet the comfort conditions quantification of the energy for cooling is either based on the number of corresponding Cooling Degrees (similar to the number of Heating Degrees) or resulting from a iterative numeric calculation (as done in this study with the calculation program TRNSys) driven by maintaining the comfort level in the building at a given comfort temperature.

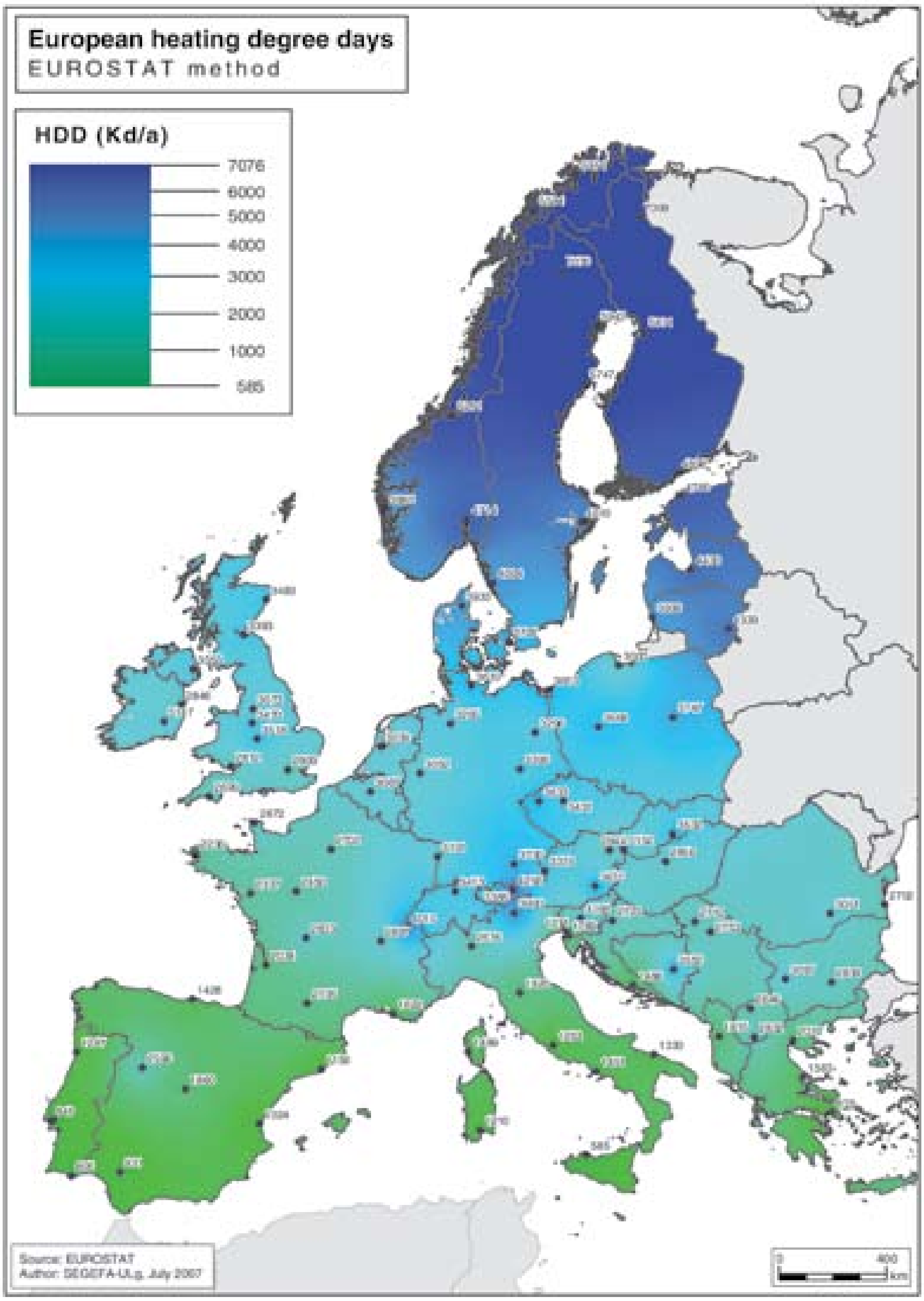
During preparation of this study EUROSTAT was working on a methodology to calculate cooling degree days. Because it had not been finalized, the methodology as applied in the US (ASHRAE) was used. Although meanwhile the US switched to a different approach developed by PNNL this does not really affect the conclusions of the study. The use of HDD and CDD for energy modelling is an approximation of reality, but acceptable for the purpose of the report.

The calculation methodology for HDDs and CDDs and a table of results for selected European cities is described in Annex 1.

3.1.2 EUROPEAN HEATING DEGREE DAYS MAP

Based on the calculations of heating degree days, the following European map can be drawn:

Figure 5: European heating degree days map (EUROSTAT method)

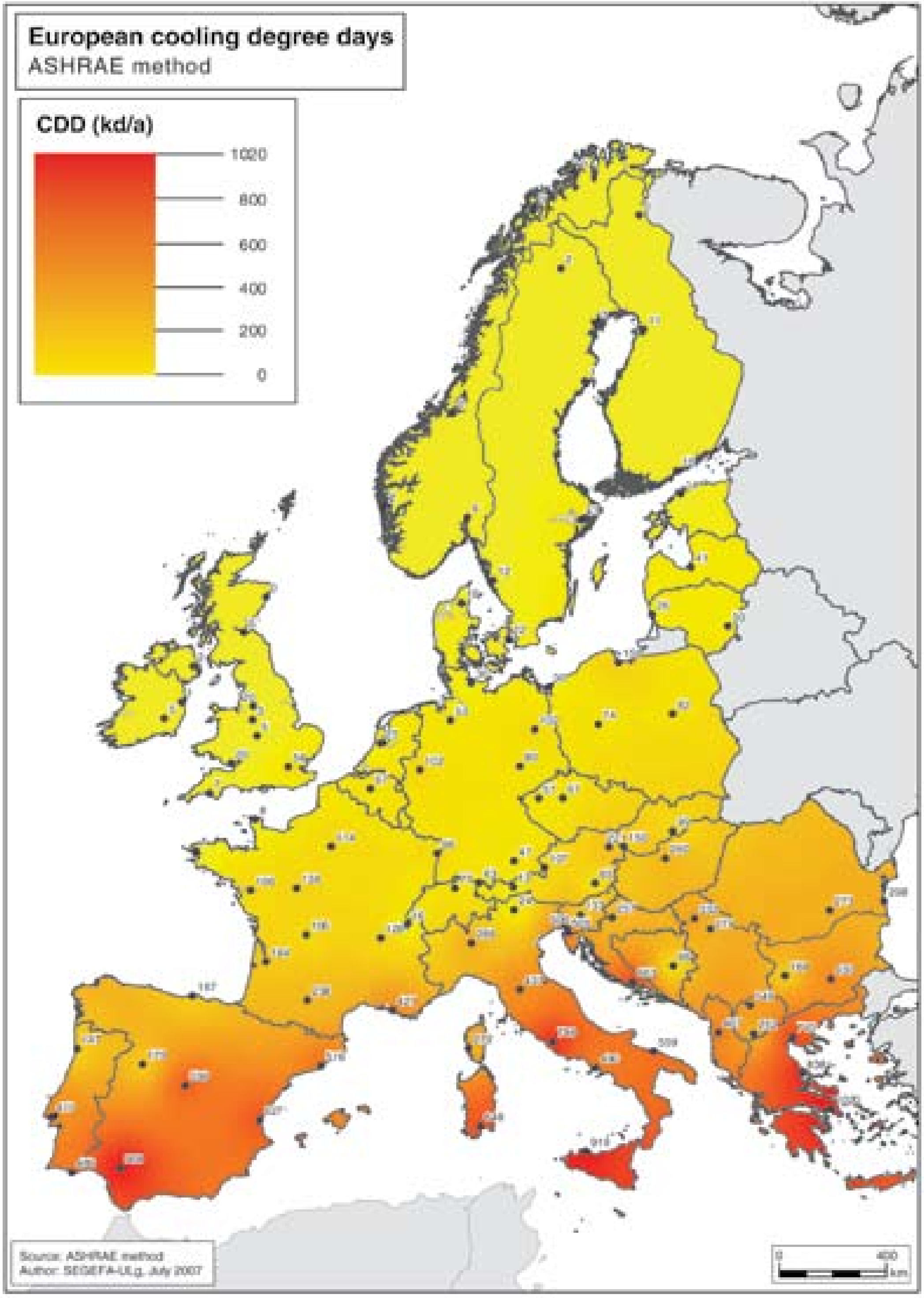


It should be noted that due to the limited number of cities included in the map, the development of HDDs cannot fully represent all regional details.

3.1.3 EUROPEAN COOLING DEGREE DAYS MAP

Similarly, the following European map for cooling degree days can be drawn:

Figure 6: European cooling degree days map (ASHRAE method)



It should be noted that due to the limited number of cities included in the map, the development of CDDs cannot fully represent all regional details.

4] INSULATION AND COOLING

The Ecofys report “Mitigation of CO_2 Emissions from the Building Stock – Beyond the EU Directive on the Energy Performance of Buildings” showed in an excursus, that insulation can, besides saving energy in the heating period, also save cooling energy in southern climates during summer. To assess the effects of added insulation on cooling demand in hot climates and the resulting influence on cost-efficiency of insulation measures, calculations have been performed with the thermal simulation programme TRNSYS.

In a first step, calculations have been performed for southern Europe for a standard terrace house (attached building) and multifamily house with typically high mass, average internal gains, external shading, natural ventilation, to cover the assumed average situation of a single building in southern Europe which already applies reasonable passive cooling strategies. The geometries have been adopted from the standard houses used in previous Ecofys reports (Ecofys II to VI). The starting point for the assessment of influence on cooling energy demand from added insulation is described in the following:

Reference buildings:

> Single family house (SFH): Terrace house with 120 m² usable floor area
> Multi family house (MFH): Building block with 1.600 m² usable floor area

Both reference buildings were assumed to have the following characteristics:

> Building materials: brick walls, concrete roof deck and floors, roof with light coloured covering
> Internal gains: 3 W/m²
> External shading of windows (75%)
> Natural ventilation
   - Average air-exchange rate day: 0,65 (infiltration and ventilation via windows)
   - air exchange rate night 2,5
> active cooling via air-conditioning system, maximum comfort temperature to keep: 25 °C
> Initial starting point: no insulation applied

In order to study the effect of insulation, internal heat gains and shadowing on the cooling demand to keep the comfort conditions in the reference buildings, the following “package of measures” was applied:

> wall: U-value reduced from 1,7 to 0,6 W/m²K
> roof: U-value reduced from 2,25 to 0,5 W/m²K
> floor: U-value reduced from 1,0 to 0,5 W/m²K

4.1 IMPACT OF CLIMATE ZONES

As the external climate conditions to a large extend determine the cooling demand, indicative analyses were carried out for the described reference buildings in Seville (908 CDDs), Marseille (427 CDDs) and Lyon (128 CDDs).The results are given in kWh of cooling energy demand per m² living area[2].

Figure 7: Energy demand for cooling for a SFH in Seville, Marseille and Lyon

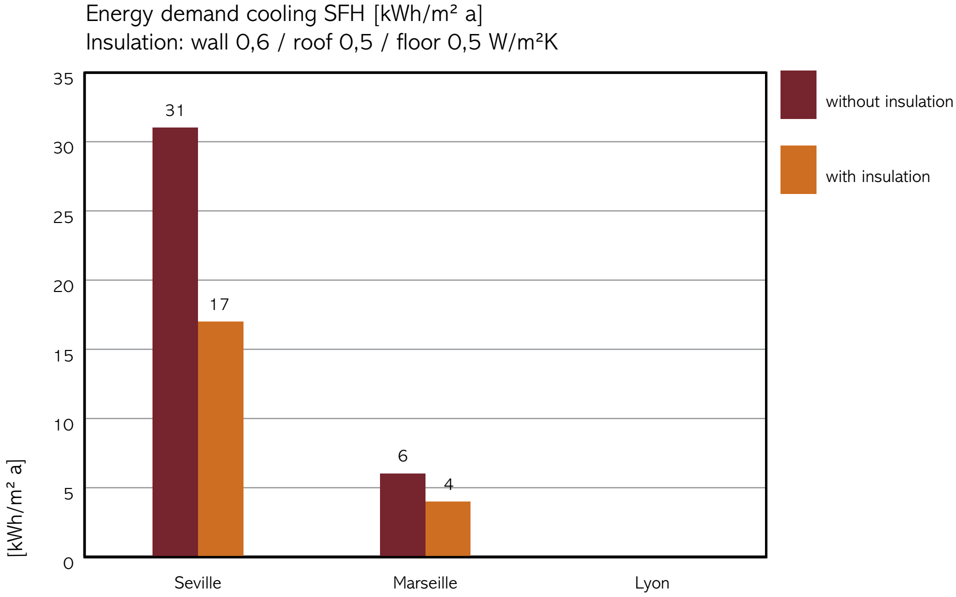
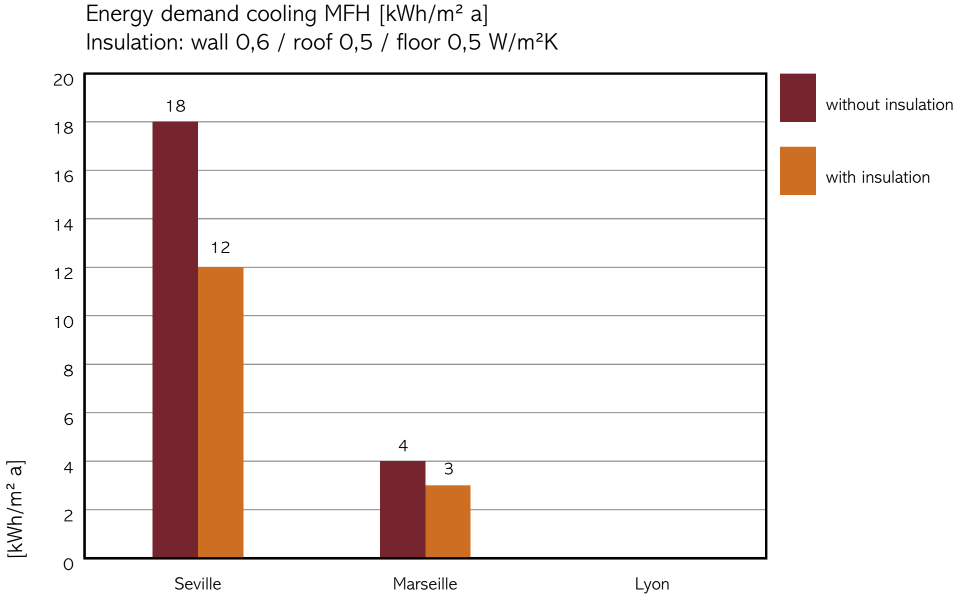


Figure 8: Energy demand for cooling for a MFH in Seville, Marseille and Lyon



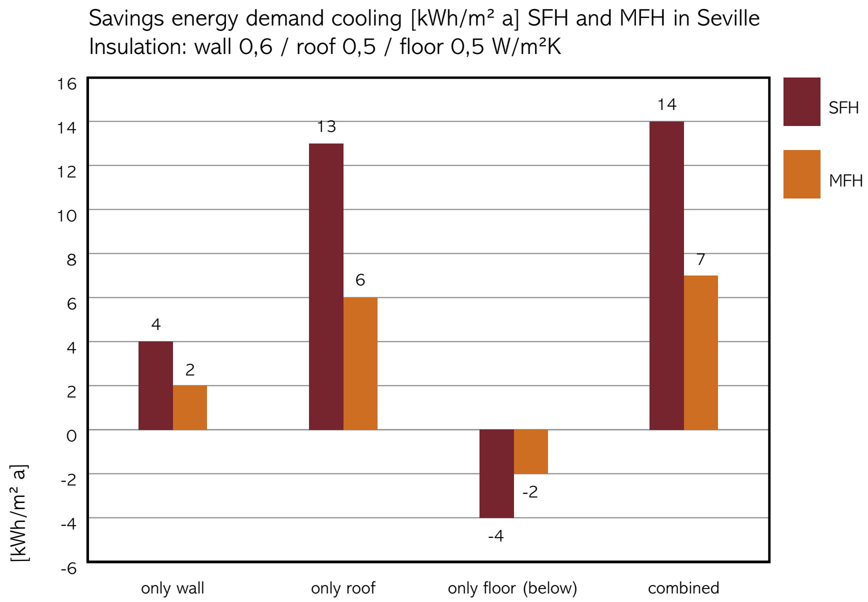
[2] The energy demand in kWh/m² a refers to m²-usable floor area: to 1 m² from the 120 m² of the SFH and to 1 m² of the 1600 m² of the MFH.

The results show that substantial savings of cooling energy demand can be realised by adding insulation. At the same time it is apparent that the total demand for cooling energy in residential buildings is significantly decreased in moderate climates like Lyon compared with hot climates like Seville.
The calculated cooling demand of zero for Lyon thereby reflects the fact that the average indoor temperature of the whole building in the absence of active cooling systems does not exceed 25°C during summer. The situation can be different for a single room apartment within the building with a south facing roof.

4.2 IMPACT OF BUILDING COMPONENTS

The effect of the single measures, insulating the external walls, roof or ground floor is described in the following graphs.

Figure 9: Energy savings from insulation measures in Seville



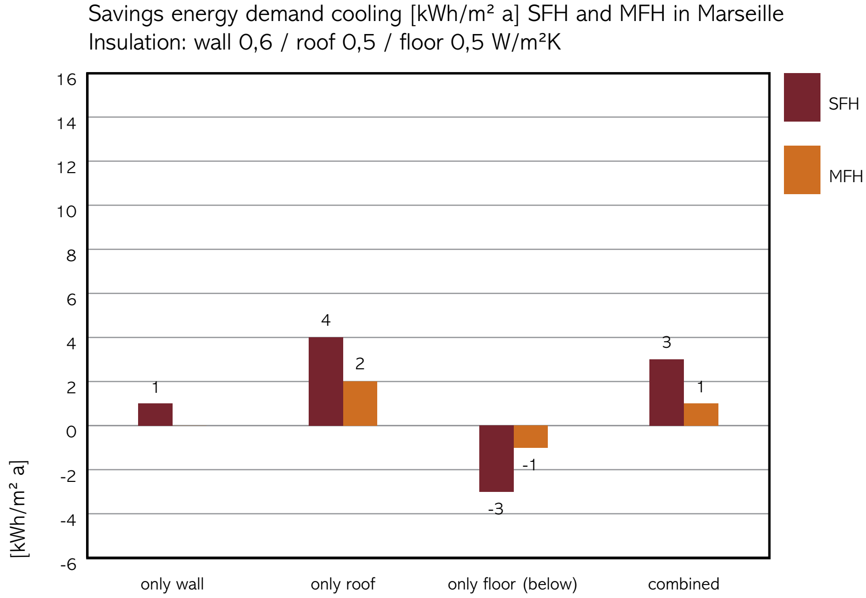
When looking at the single measures wall, roof or floor insulation on their own, it is apparent that they contribute in different ways to the savings of the combined insulation measures.

The insulation of a wall of the reference single family house in Seville reduces the cooling energy demand by 4 kWh/m² year. Surprisingly the effect of roof insulation is positive. This is due to the particularly high temperatures of the roof caused by solar radiation which leads to higher surface temperatures and a consequential thermal insulation benefit.

The insulation of the ground-floor results in an increase of cooling demand in hot climates. This is caused by the reduction of the cooling effect because of the relative cool temperatures of the ground in the summer situation. On the other hand during the winter season the insulation of the ground floor results in heating-energy savings. Therefore the recommended U-values in this study take into account the effect of insulation on heating and cooling demand. However, regarding floor insulation further restrictions could be given to meet demands such as the acoustic comfort (contact noise), building physics (level of surface temperature given the humidity conditions in order to avoid condensation or desired fast response-time of floor heating) that might require more insulation (a lower U-value) for floors.

An analogous effect of insulation on cooling demand, yet at a lower level, can be found for a single family house in Marseille, see Figure 10

Figure 10: Energy savings from insulation measures in Marseille



For Lyon it could already be concluded from Figure 7 and Figure 8 that there is practically no cooling demand for the residential buildings as described and that the effects of the insulation of the roof, exterior walls or floor on the cooling demand can be neglected.

4.3 SENSITIVITY RELATED TO OTHER FACTORS

In a third step a sensitivity analysis was carried out to assess the impact of different situations concerning external shading, internal heat gains, ventilation strategy and thermal mass on the cooling demand, in relation to the degree of insulation applied.

The following scenarios have been simulated:

- No external shading of windows (reference situation: 75% shading)
- Higher internal gains of 5 W/m² (reference: 3 W/m²)
- No night ventilation (reference situation: air exchange rate night: 2,5)
- Low mass wood-frame-buildings (reference: bricks and concrete)

The results of the sensitivity analysis for the reference single family house (SFH) and the reference multi family house (MFH) in the three assessed locations can be seen from the following figures.

Figure 11: Sensitivity analysis cooling energy, SFH Seville

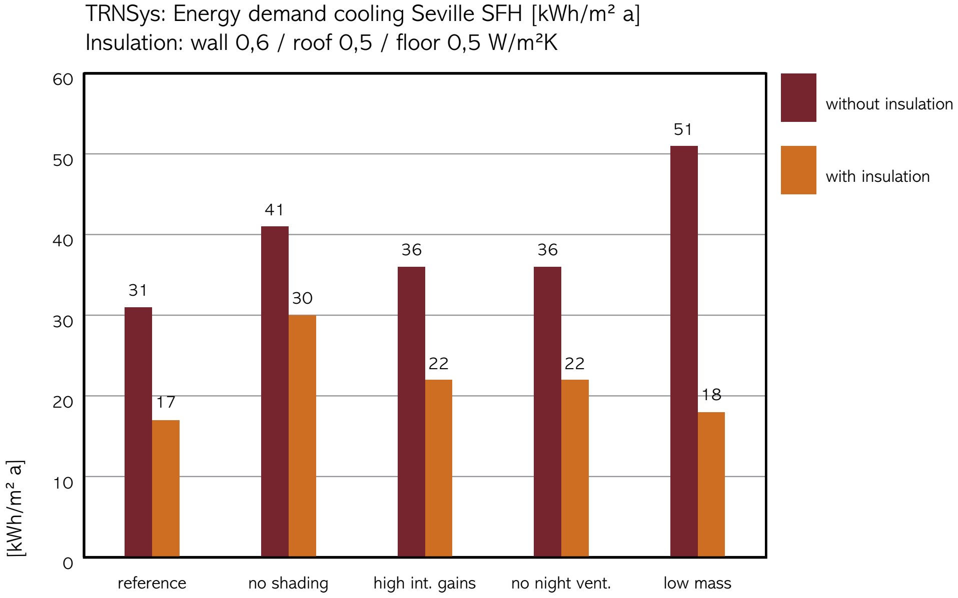
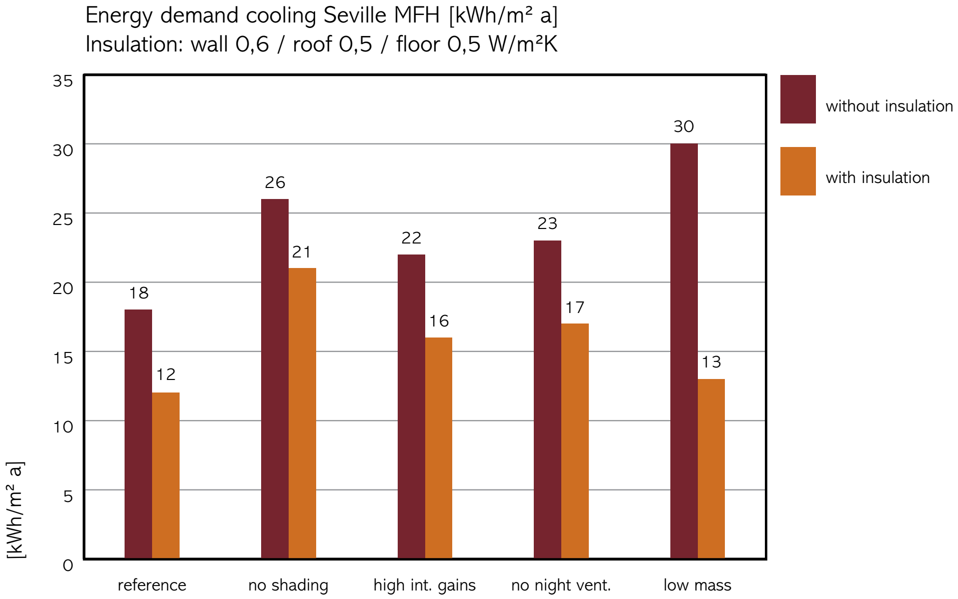


Figure 12: Sensitivity analysis cooling energy, MFH Seville

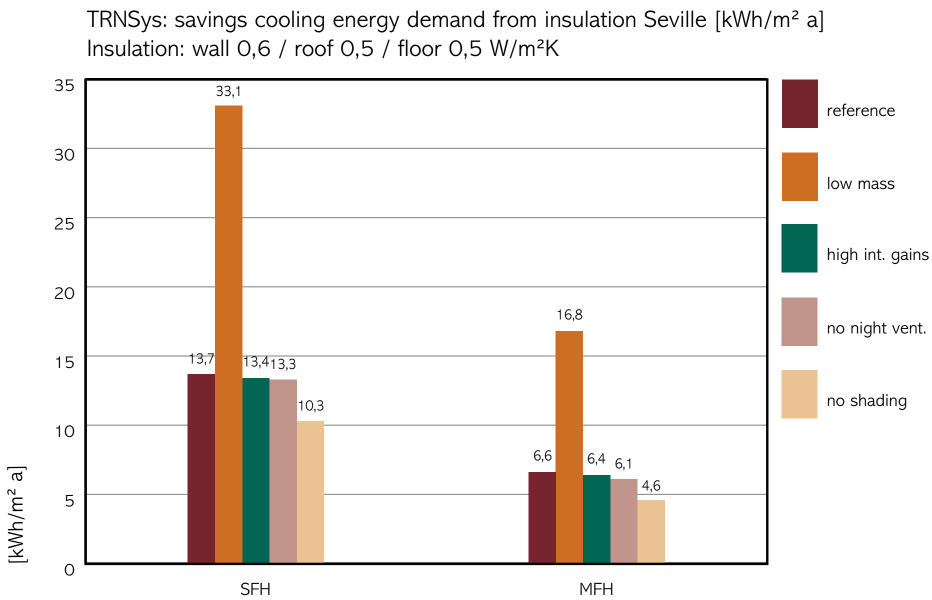


When looking at the total energy demand for cooling, it is immediately apparent that traditional passive cooling strategies like, external shading, reduction of internal heat loads, night ventilation and high building mass (as achieved in the reference situation) are effective measures to decrease cooling energy demand. This is the case for both single - and multifamily houses. Beyond that, increased insulation levels lead in all the cases described (reference-situation and in the combined measures of the sensitivity analysis) to a further reduction of cooling energy demand in the summer situation.

This means that the same insulation material that reduces heat losses of the building during winter also reduces cooling energy demand in the summer situation by reducing the heat transfer from hot outside environment to the chilled internal living areas of the house. This can be somewhat different from the feeling that people might have when thinking of wearing for example a pullover during summer. But in this case the high internal gains of a body are the reason for the resulting discomfort.
The situation within an insulated house can better be compared to a thermos bottle, which keeps beverages hot in winter and cool in summer by reducing the heat transfer from hot to cold temperatures - regardless its direction.

Focusing on the cooling energy savings resulting from added insulation (difference between U-values for situations with and without insulation, shown in Figure 11 and Figure 12) the following picture can be drawn.

Figure 13: Sensitivity analysis cooling-energy savings from insulation in Seville



It can be concluded, that the influence of insulation on cooling demand is relatively constant in the different situations with the exception of technical premises like buildings with low mass (leading to significantly larger saving potential) and buildings with no external shading equipment (reducing the savings potential). This leads to the conclusion, that the benefit of insulation regarding cooling is quite robust against the different behaviour of tenants who might have higher internal gains from e.g. electric applications[3] or who do not use ventilation strategies such as night ventilation. This is an important conclusion when examining the figures below, which show the effect of insulation on cooling demand resulting from calculations of optimal U-values based on cost efficiency.

The above also is valid for the climate conditions in Marseille and Lyon, which were taken as indicative examples.

[3] Concerning internal gains the situation can differ for non-residential buildings (esp. office-buildings) where very high internal gains from computers, lighting etc. occur which might reduce, or even reverse, the positive effect of insulation on cooling demand.

Similar effects, at a lower level, can be observed for the scenarios investigated for Marseille.

Figure 14: Sensitivity analysis cooling energy, SFH Marseille

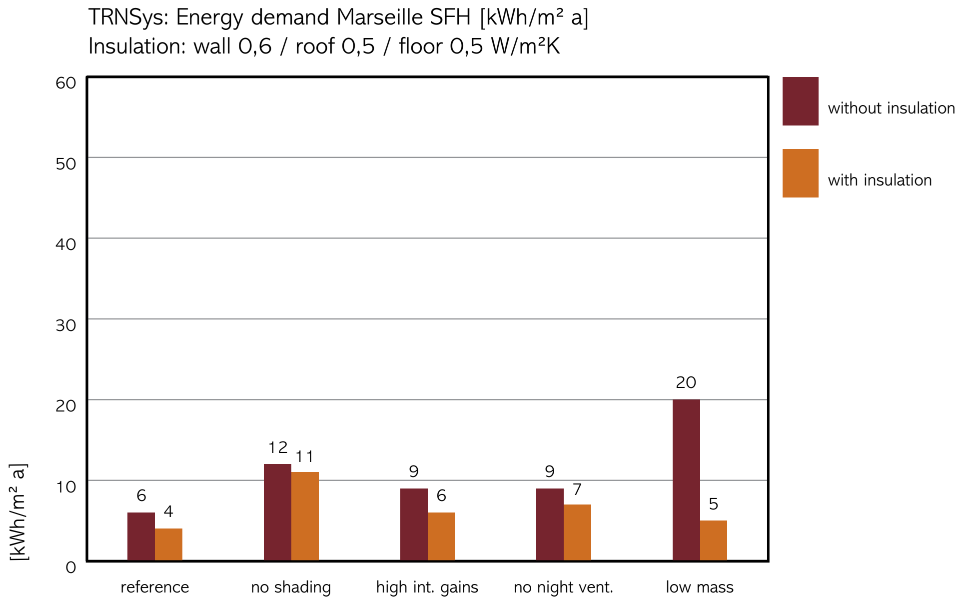
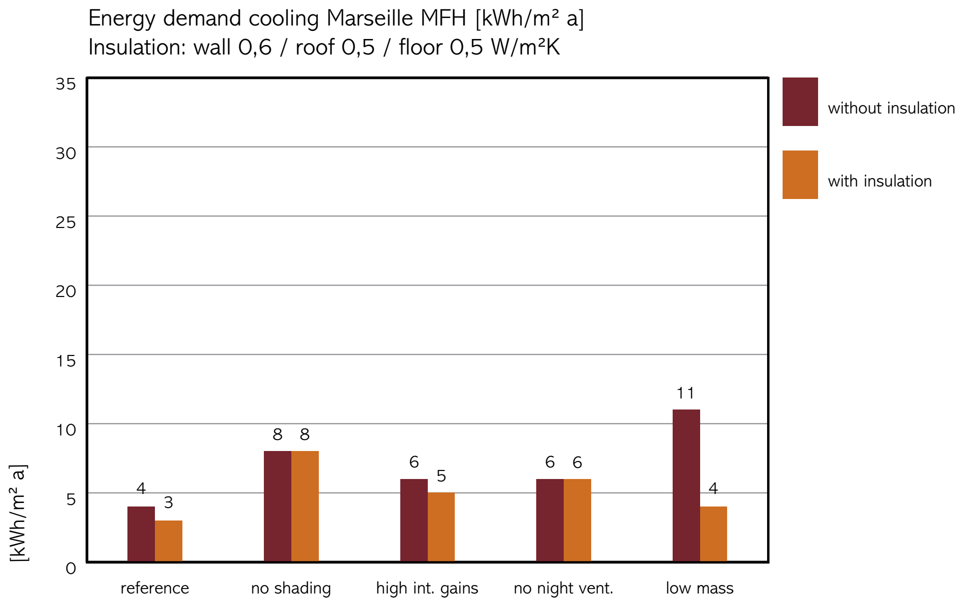
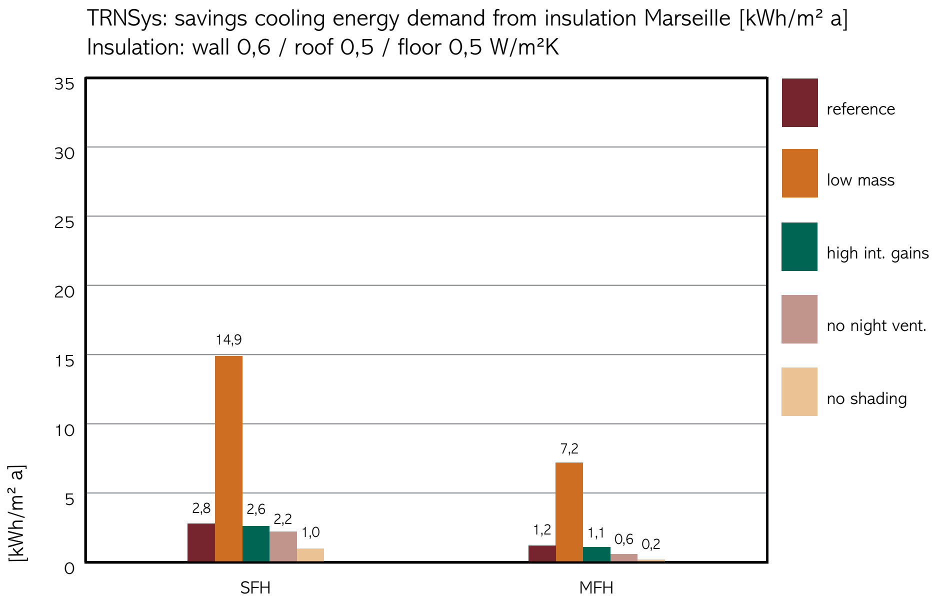


Figure 15: Sensitivity analysis cooling energy, MFH Marseille



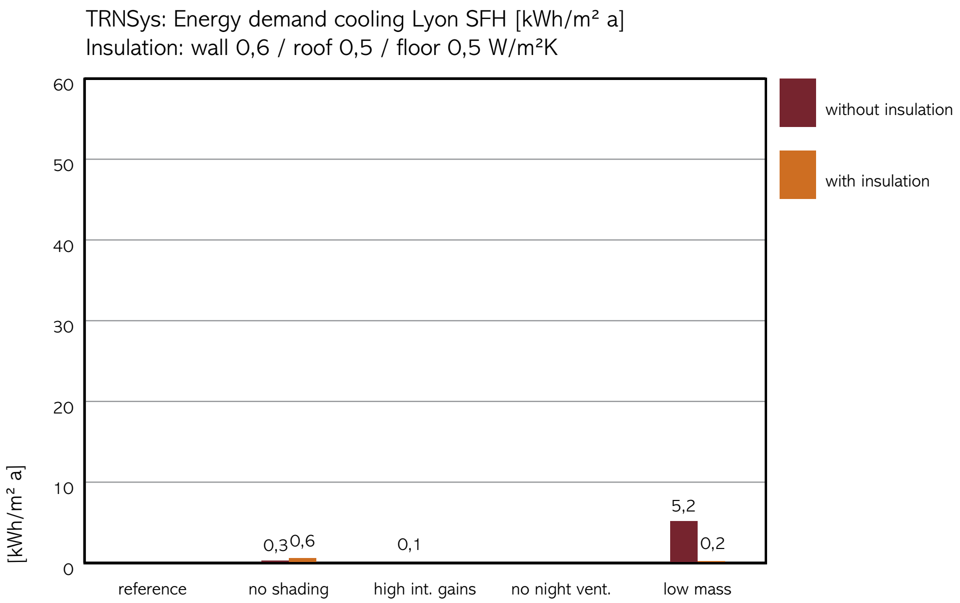
With the milder climate in Marseille, the total cooling demand is reduced. The lower number of cooling degree days also leads to a (relative to the reference-situation) higher impact of the insulation situations described in the sensitivity analysis, as can be seen from the next graph.

Figure 16: Sensitivity analysis cooling-energy savings from insulation in Marseille



The following graphs describe the situation in Lyon.

Figure 17: Sensitivity analysis cooling energy, SFH Lyon



In Lyon there is no cooling demand for the residential buildings described in the reference situation, with or without insulation. A small increase of cooling demand (from 0 to 1 kWh/m² a) due to added insulation can be observed for the unfavourable situation with no external shading. Significant effects on cooling demand can only be seen in case of the low-mass building, where added the insulation eliminates the cooling demand.

A similar picture can be drawn for a multi-family house in Lyon, see Figure 18.

Figure 18: Sensitivity analysis cooling energy, MFH Lyon

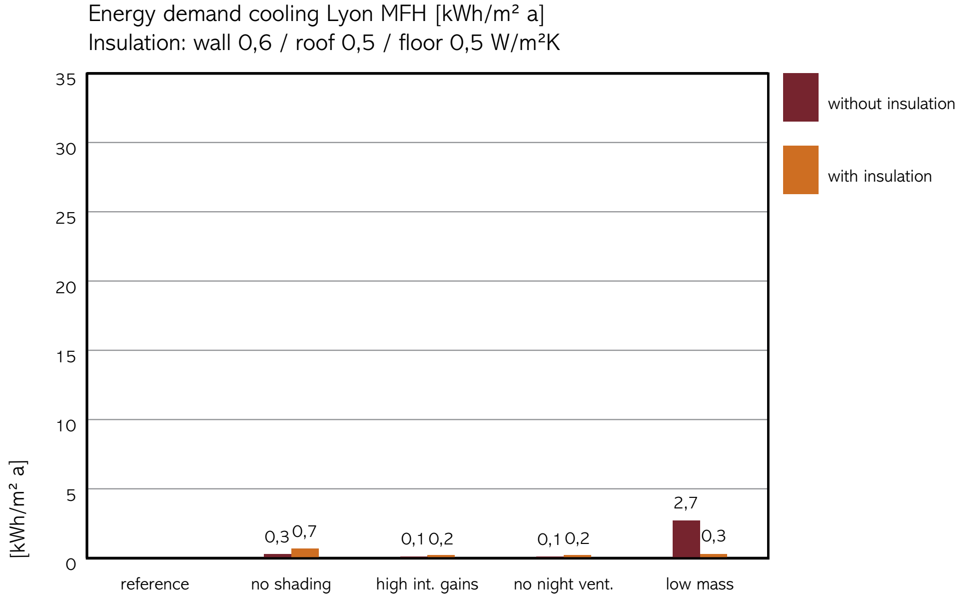
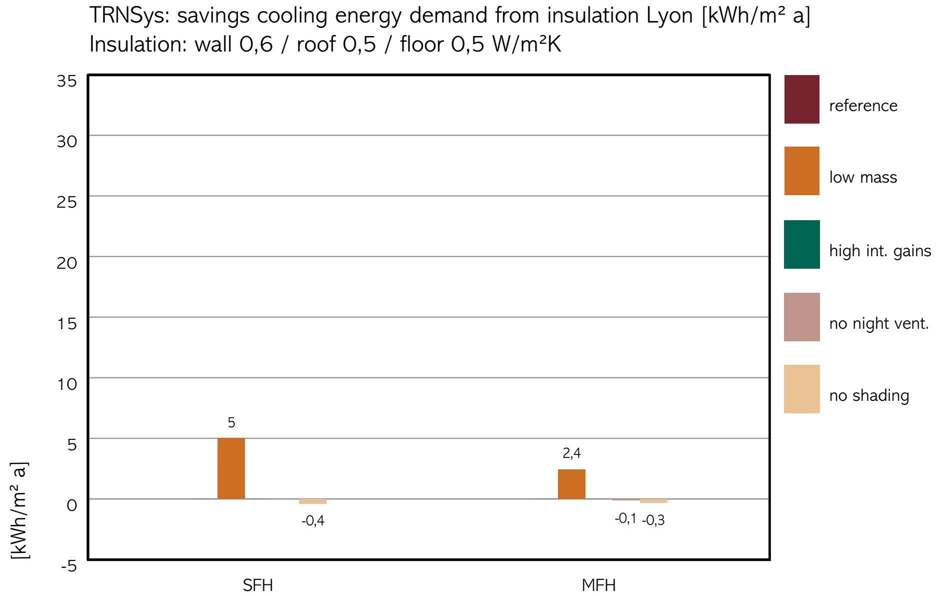


Figure 19: Sensitivity analysis cooling-energy savings from insulation in Lyon



Looking at the saving-potentials, the cooling issue plays only a minor role in the moderate climate of Lyon for buildings with low mass but added insulation can avoid the demand for active cooling. However also see explanations in chapter 4.1.

4.4 CONCLUSIONS ON ENERGY DEMAND FOR COOLING

The above calculation carried out to show the effect of insulation on cooling demand demonstrates that:

- regardless of the climate conditions (climate zones) a sound package of insulation measures reduces the energy demand for cooling (in residential buildings).

This conclusion is also supported by the results for the cooling demand, if the calculated optimum U-values (see values described in table below based on the results of chapter 5 “U-values according to cost-efficiency”) are used. The 3rd and 4th bar in Figure 20 illustrates that the preliminary approach with an improving insulation package was too conservative. The optimum U-values for roof, wall and floor demonstrated may seem rather unusual (see Annex 2) but prove that considerable contributions in the reduction of the cooling demand can be realised in buildings.

Table 1: Overview U-values: reference, package 1 and calculated financial optimum for two different energy price scenarios

U-value [W/m² K]	Reference	Package 1 introduction chapter 4	Scenario WEO			Peak price scenario		
			Seville	Marseille	Lyon	Seville	Marseille	Lyon
wall	1,70	0,60	0,39	0,29	0,21	0,32	0,26	0,18
roof	2,25	0,50	0,27	0,23	0,18	0,24	0,19	0,15
floor	1,00	0,50	1,44	0,43	0,28	1,06	0,39	0,23

Figure 20: Impact of optimum U-values on cooling demand, SFH

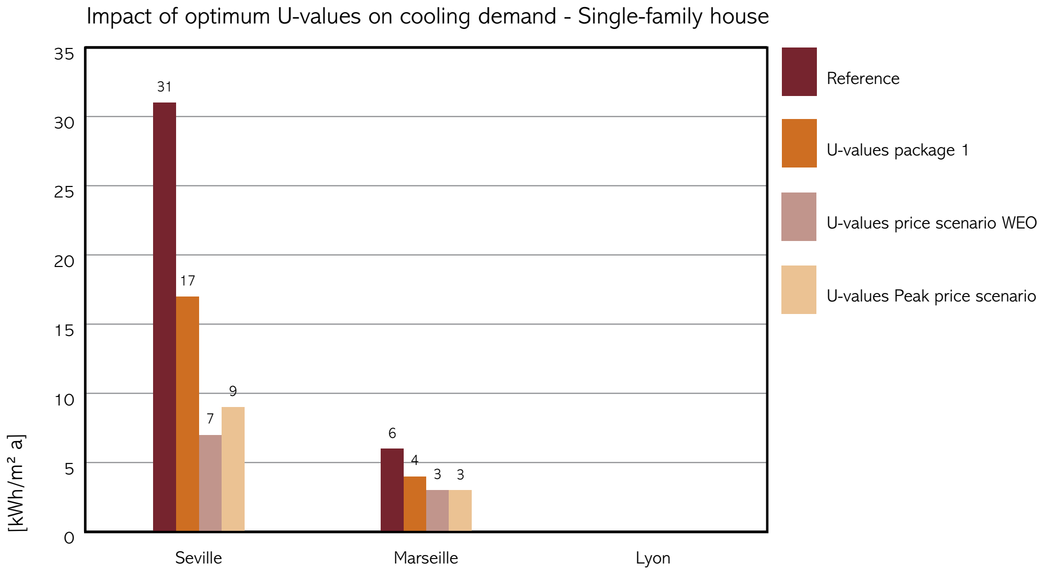
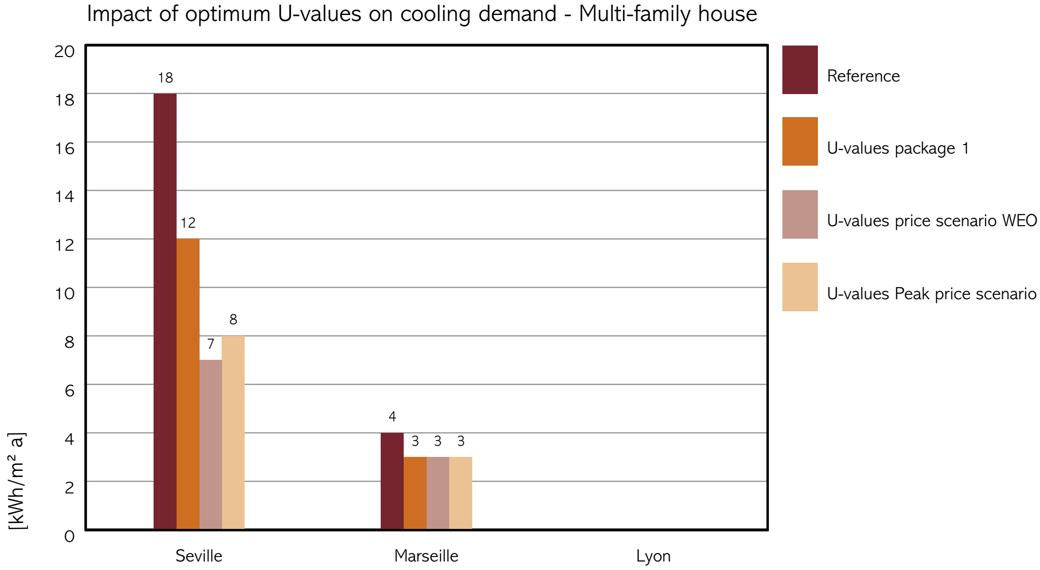


Figure 21: Impact of optimum U-values on cooling demand, MFH



It is clear that the calculated U-values in both price Scenarios (WEO and Peak price scenarios) lead to further cooling energy savings, compared to the insulation package as assessed in chapter 4 "insulation and cooling". A slight increase of cooling demand can be observed from scenario WEO to the Peak price scenario for Seville, due to the higher insulation of the floor. The optimum U-value for the floor in the Peak price scenario is calculated for the optimum from cooling AND heating. As the heating demand in this case is requiring the lowest U-value (1.06 W/m²K), this is resulting in higher energy demand for cooling only. The total energy demand over the seasons is meeting the optimum. For the assessed buildings in Lyon, there is practically no cooling demand within the calculation methodology (one zone model, hourly values), regardless the chosen insulation package, see also chapter 4.1.

> Looking at the different components of the building envelope, the cooling-energy savings from increased insulation are most significant for roof-insulation, followed by insulation of exterior walls. The insulation of the ground floor increases cooling demand in hot climates with a sound package of floor, wall and roof insulation still resulting in a significant reduction of cooling energy.

> Even under less favourable conditions (no shading, higher internal gains or a sub-optimal ventilation regime to evacuate excess heat) insulation reduces the energy demand for cooling down to the designed comfort temperature.

> The positive effect of insulation on the cooling energy demand seems to be especially the case for low mass buildings, where added insulation can to a large extend "replace" the thermal inertia of a massive building. In the study the case "low mass building" is not further elaborated and has not been taken into account in the U-value maps.

5] U-VALUES ACCORDING TO COST-EFFICIENCY

5.1 METHODOLOGY

For an economic assessment of insulation measures (resulting from lower U-values), not only investments but also the operational cost savings achieved (energy costs) are relevant. The methodology chosen, which is analogous to that of the previous Ecofys reports (Ecofys reports III to VI), allows comparison of the different costs over the whole life cycle of energy saving measures. The main elements of these life cycle costs are capital costs and annual running costs.

> Capital costs

Capital costs result from the investment in energy-saving measures. To compare the investments with the annual running costs the investments are converted into constant annual capital costs. Therefore the investment costs are multiplied by the equivalent annual cost factor or annuity factor, which is based on the lifetime of the measure and a selected interest rate:

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

Symbol	Parameter	EU15 + Norway + Switzerland	NEW12
a	Annuity factor	0,0578	0,0726
i	Interest rate	4%	6%
n	Service Lifetime	30 yrs	30 yrs

The chosen interest rates and service lifetimes are consistent with the previous Ecofys studies on the cost-effectiveness of energy-efficiency measures in the EU building stock (Ecofys III to V). The applied interest rates are default social interest rates.
It is however important to note that the applied social interest rates may differ significantly from interest rates or expected returns on investment for individuals or companies, i.e. the cost optimum for society is often different from an investor's optimum. Public policy usually attempts to minimise costs to society.

The report differentiates between the investment costs in fixed costs and additional costs per centimetre of insulation, as shown in the following equation.

$$IC = IC_f + IC_{add} * d$$

IC	Investment costs
IC_f	Fixed costs
IC_{add}	Additional costs per cm insulation
d	Thickness of insulation

> Fixed costs

The “fixed” costs per m² represent the part of the total costs that are necessary to carry out the insulation measure, regardless of the thickness of insulation that is applied. These are for example cost for fixings, preparation of the surface etc. The fixed costs per m² are very much dependant on the insulation technique, for example insulation in wood frame facades or inclusion in a thermal composite system. The investments (cost per m²) referred to include material and labour costs as well as appropriate taxes (VAT).

> Additional costs per cm insulation

The additional costs per centimetre of insulation are the costs necessary for every additional centimetre. The investments (cost per m²) referred to include material and labour costs as well as appropriate taxes (VAT).The costs per additional centimetre thickness can be assessed, for example, by looking at the total costs of a insulation system with 10 cm and with 30 cm and dividing the difference in costs by 20 (increase in insulation thickness). The result can be considered to be the same for both retrofit and the new buildings[4]. The fixed costs however may be different for new buildings and for retrofit.

Annual running costs

For the annual operation costs the energy cost savings for heating and cooling are taken into account. Therefore the energy savings are multiplied by the respective energy costs, which are specified in section 5.3.

Energy savings heating

The energy-savings of different insulation measures for heating applications are calculated according to the following equation:

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

ΔE	[kWh/m² a]	Energy-savings (per m² surface area of the construction element)
HDH	[kKh/a]	Thousands of Heating Degree Hours (per year) = HDD*24/1000
ΔU	[W/m²K]	Difference in U-values before and after retrofit
η	[-]	Efficiency of heat generation and distribution

Energy savings cooling

To evaluate the energy saving for cooling purposes in hot climates, calculations have been performed with the thermal simulation programme TRNSys.

Economic optimum and U-value maps

To find the economic optimum of insulation measures, it is common to use graphs which represent the life cycle costs which vary depending on the insulation thickness. Usually these graphs show a minimum at a certain applied insulation thickness which is the economic optimum, leading to a specific U-value of the component; the optimal U-value.

In the following chapters the graphs show the economic optimum value in case insulation is applied to external walls, roof and ground floor. The optimal U-values based on cost efficiency have been calculated for 100 cities in Europe.

[4] An exception is the insulation of cavity walls in retrofit applications (quite common e.g. in The Netherlands and the UK), which is done by filling the existing air gap.

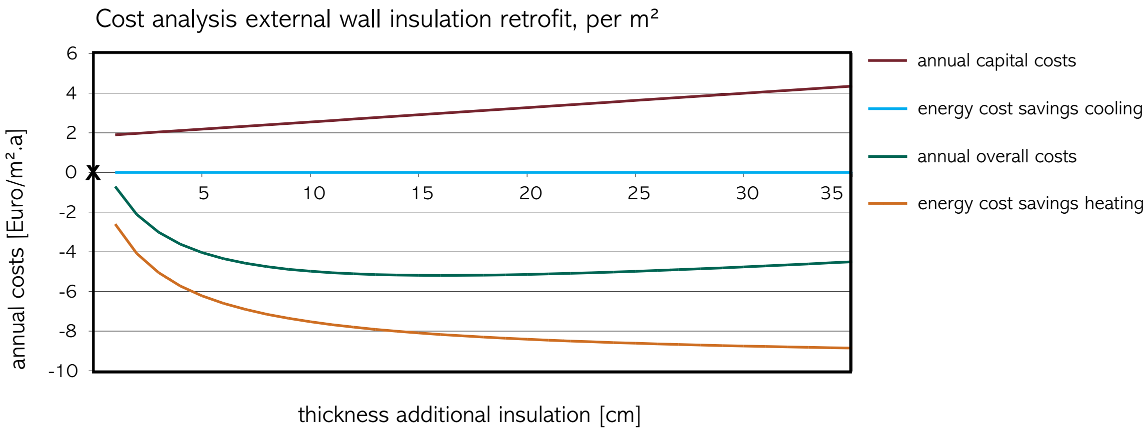
5.2 MECHANISMS OF U-VALUE OPTIMUM

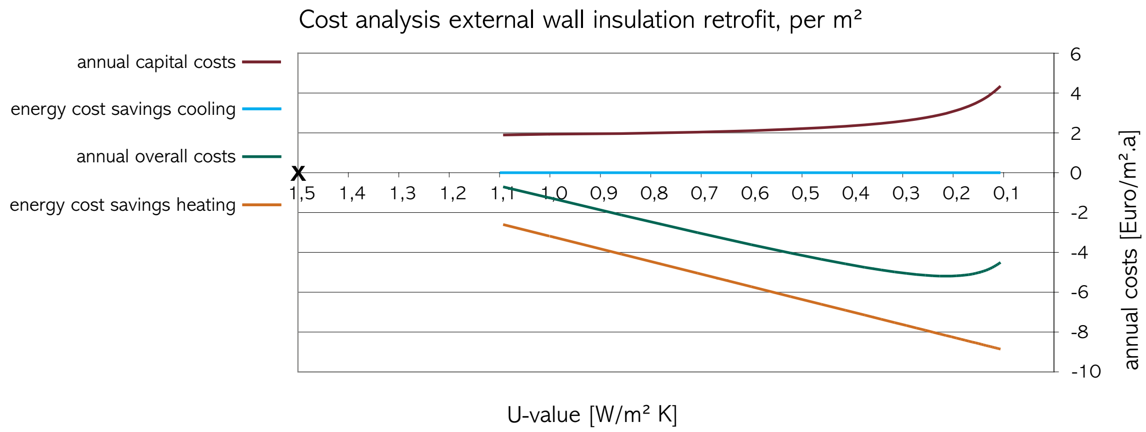
To clarify the influence of different parameters on the optimum U-value, the mechanisms which determine the U-value are described in the following text.

Principle of a determination of the U-value optimum

The two graphs in Figure 22 show the development of costs (investment in insulation) and associated savings (saved energy costs for heating and cooling) for the example of an external wall in Amsterdam. By adding up the costs and savings, a total cost-curve can be drawn, with the lowest point representing the optimum insulation solution, from an economic point of view. The same situation is described, firstly depending on thickness of insulation (first graph of Figure 22) and then depending on resulting U-value (second graph of Figure 22). In this second case, the optimum insulation level is circa. 16 cm of insulation, resulting in an U-value of 0.21 W/m²K. The optimum U-value is characterised by the lowest U-value (or: maximum insulation thickness) for which the savings of energy costs per additional centimetre are higher than the corresponding increase in annual capital costs.

Figure 22: Mechanisms of U-value optimum – base case





The curve for the cost savings shows a typical development against increasing insulation thickness with especially large savings generated by the first centimetres of insulation, (first graph in Figure 22). In the second graph, the development of savings improves in a linear way as U-value are reduced and there are corresponding energy and energy cost savings resulting from reduced heat transmission losses.

Influence of the fixed costs

The fixed costs per m², which are the result of the insulation technique, determine whether an insulation measure is cost effective (lowest point of the total cost-curve below the zero-line), which is usually the case[5], or alternatively (lowest point of the total cost-curve above) zero-line, not cost effective which might occur in case of expensive techniques/improvements or an already high insulation standard of a component, which limits the possible savings. But the fixed costs only result in an offset of the graph and determine the position of the resulting curve.

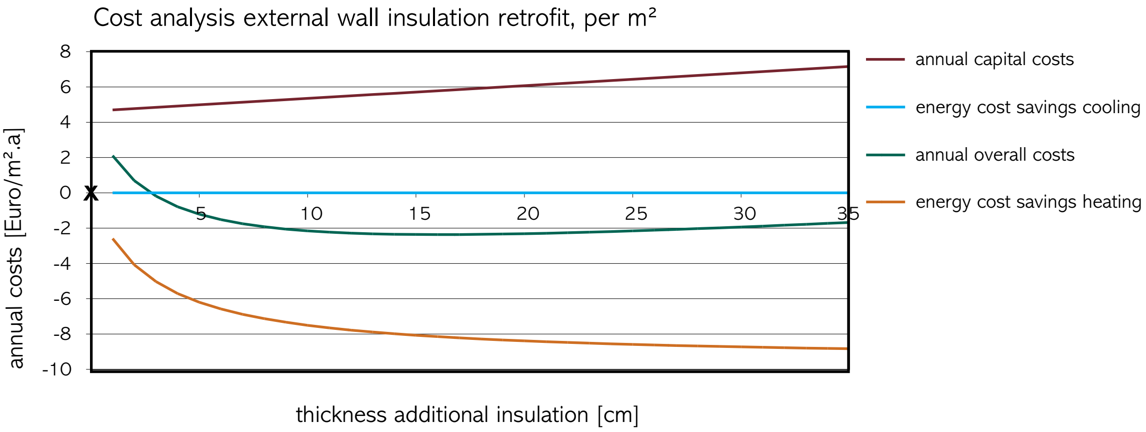
From an economic point of view, an investor will choose for an insulation measure, if the potential annual energy cost savings exceed the annual investment costs (fixed costs + additional costs for added centimetre of insulation).

If then insulation is applied, the envisaged U-value should be chosen according to the economic optimum, which on itself is independent of the level of the fixed costs.

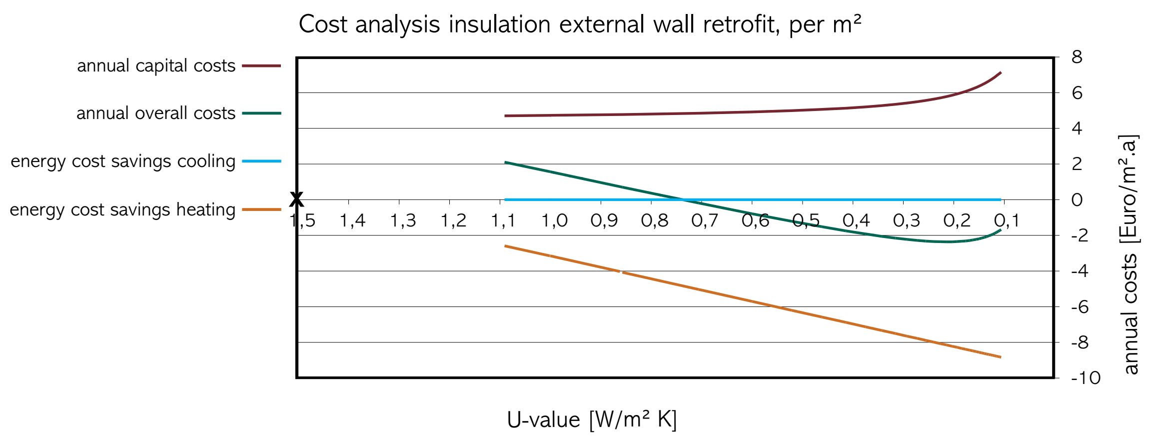
If a component however already has a rather good thermal performance (a low U-value) the additional energy savings may not exceed the annual investment costs for applying additional insulation. This might be the case in some Scandinavian situations in the existing building stock.

The optimum insulation thickness and corresponding U-value is from the investment point of view only affected by the costs of additional insulation. Of decisive importance for the optimum is the balance between the costs for an additional centimetre of insulation and the corresponding energy costs-savings. This mechanism is described in the two pictures of Figure 23, which show a theoretical situation with fixed costs per m² of 80 Euro (base case in Figure 22: 31,5 Euro per m²), with the optimum U-value still at 16 centimetres of insulation (U-value of 0,21 W/m²K).

Figure 23: Mechanisms of U-value optimum – sensitivity fixed costs



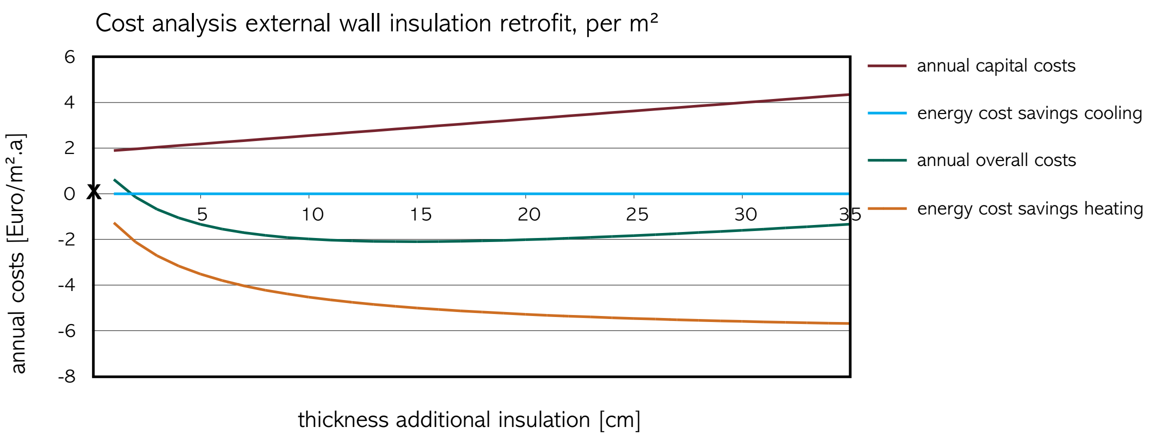
[5] as proven in the Ecofys reports "Cost-Effective Climate Protection in the EU Building Stock" and "Cost-Effective Climate Protection in the Building Stock of the New EU Member States - Beyond the EU Directive on the Energy Performance of Buildings"

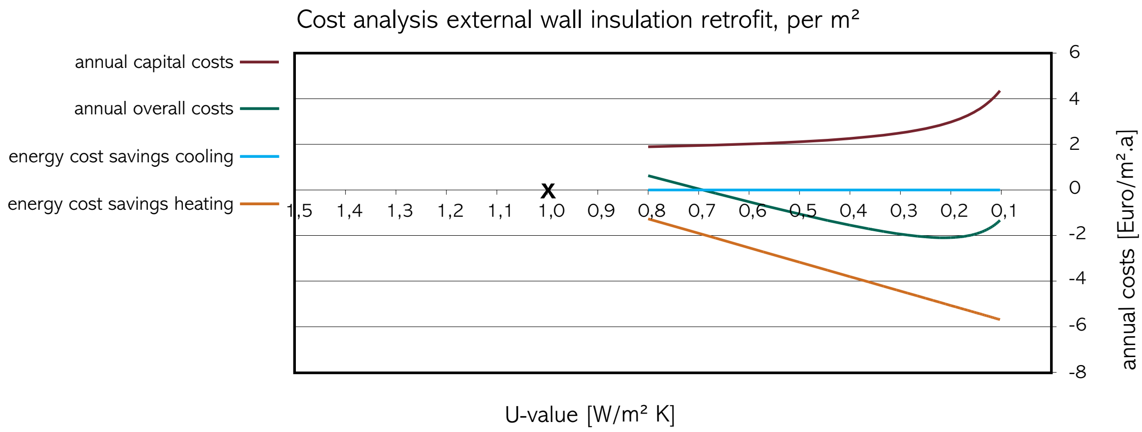


Influence of wall construction without insulation

The next two graphs in Figure 24 show the situation of the example wall assuming the existing wall already has a U-value of 1 W/m²K (starting point in base case Figure 22 examples before: 1.5 W/m²K). It can be seen that the curve for the total costs has moved upwards, representing the reduced cost efficiency of the measure. This is similar to the previously mentioned effect of a higher level of fixed costs per m². However in this case the U-value **optimum** is still at 0.21 W/m²K. The determining factor is again the lowest U-value (or: maximum insulation thickness) for which the savings of energy costs per additional centimetre are higher than the corresponding increase in costs. This optimum U-value is not affected by the "history" of U-value-development of the respective component.

Figure 24: Mechanisms of U-value optimum – sensitivity starting point U-value





Parameters affecting the optimum U-value

To summarize the above mentioned processes, the optimal U-value from an economic point of view (answering the question which U-value represents the best economic value, compared to less or more insulation added) does **not** depend on:

- The fixed costs per m² (Euro/m²)
- The U-value before carrying out the insulation measures

These parameters determine, whether it is an economic benefit to add insulation to a building (vertical position of the cost curve).

The U-value optimum if insulation is applied depends on:

- The investment cost for additional centimetres of insulation (Euro/cm and m²)
- The climate conditions, defining the amount of energy saved by adding insulation
- The costs of energy saved (Euro/kWh)

These parameters determine the shape of the optimum curve and thus the position of its optimum.

Following these processes, the following important conclusions can be drawn:

> The optimum U-value, if insulation is applied, is for a given location the same for new buildings and for retrofit actions, this is despite differing fixed costs per m² and different U-value starting points (both of which do not affect the optimum of the cost curve) but usually with the same costs per additional centimetre and the same local climate conditions and energy costs.

> The U-value optimum is also quite robust concerning different application methods that affect the fixed costs per m² but are rather similar regarding costs per additional cm of added insulation.

The inputs used for the data which affect the U-value optimum are described in the following chapter.

5.3 INPUT CALCULATIONS

In the EU, rather different starting points are given for the calculation of optimal U-values for cost efficiency purposes. In the first place this are the climate conditions, which have been taken into account for 100 selected cities, based on climate data from METEONORM.

The factors energy prices, fuel mix, U-values before applying insulation and investment costs have also been taken into account, according to the definitions and data-inputs used in previous Ecofys-studies, expressed as average values in zoned levels for:

- cold zone of EU15 (+ Norway)
- moderate zone of EU15 (+ Switzerland)
- warm zone of EU15
- New EU8 (+ Romania, Bulgaria, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, Macedonia and Albania)

To be able to draw a complete European U-value-map, the major factors influencing the validity of the 4 zones have been checked during the present study for the additional countries (mentioned above in brackets); this goes beyond the previously assessed EU15 and New EU8. As a result, the additional countries can be allocated to the 4 zones with reasonable accuracy. In the following chapters, the inputs for the following calculations are described. In Annex 2 the calculated results for 100 cities in Europe are given.

5.3.1 ENERGY PRICES

The Ecofys-study “Sensitivity Analysis of cost effective Climate Protection in the EU Building stock” described 5 scenarios (1 to 5). For the current report a price scenario was made on the basis of the forecasts from the new available IEA world energy outlook 2006. Additionally the results were calculated for the peak price scenario from the Ecofys-study “Sensitivity Analysis of cost effective Climate Protection in the EU Building stock”. For both scenarios, the average energy prices for the timeframe from 2006 to 2036 were used as input for the cost-calculations.[6]

Scenario “WEO reference”

> The assumption of the average oil price for the time period 2006 to 2036 is derived from the current IEA World Energy Outlook 2006, which describes a substantially higher scenario for the oil price until 2030 than the World Energy Outlook 2005. The average increase in costs is assumed to be 1,5% p.a.

> With the price for gas and district heating being dependent on the oil price, these values have been adapted accordingly.

> Several reliable studies assume only a moderate increase of the electricity price in the long term. Data from EUROSTAT statistics have therefore been projected to the future with an 1,5% increase per year. The same approach was used for wood prices.

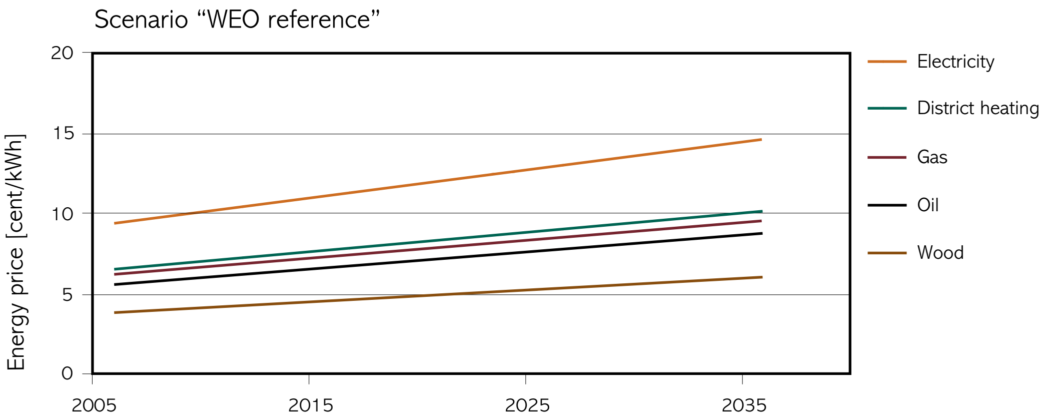
[6] The energy prices reflect the price per kWh for end-consumers including all taxes

Table 2: Scenario "WEO reference"

Increase rate	1,5%	Average 2006-2036
Gas	cent/kWh	7,73
Oil	cent/kWh	7,06
Electricity	cent/kWh	11,83
District heating	cent/kWh	8,14
Wood	cent/kWh	4,83

As prices and forecasts for coal used in private household are difficult to obtain and coal is also rarely used (only to some extent in the NEW8 countries) the price of coal per kWh is estimated parallel to the price for heating oil).

Figure 25: price development Scenario "WEO reference"



Peak price Scenario

> In this scenario, it was assumed the peak price from August 2005 for Brent crude oil at the stock exchange (70 US dollar/barrel) becomes the average price in the future. Please note that the price of 70 USD/barrel corresponds in the year 2032 to 117 US dollar in nominal terms.

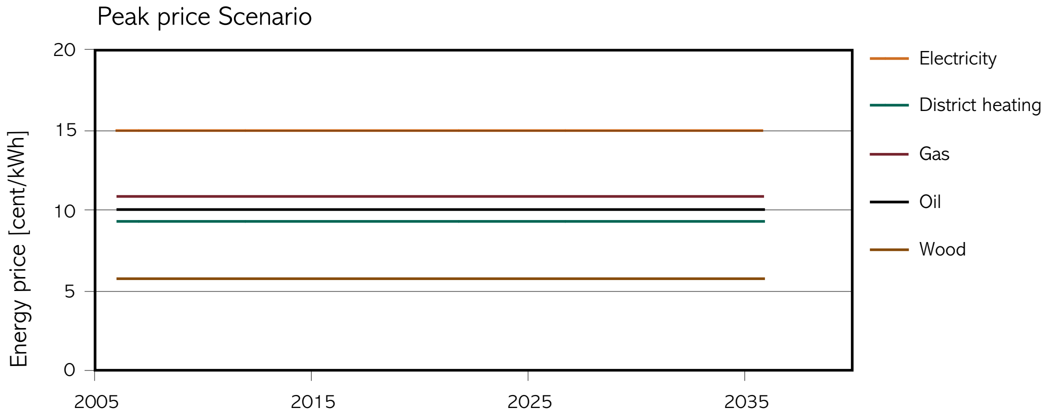
> Thereby the usual price difference from the prices paid at the stock exchange to the final customer (paying for litres of oil delivered) was taken into account.

> The other energy carriers were set at the value calculated in Scenario 4 (high price scenario of the report "Sensitivity Analysis of cost effective Climate Protection in the EU Building stock") for the year 2032.

Table 3: Energy Prices Peak price scenario

Increase rate	1,5%	Average 2006-2036
Gas	cent/kWh	10,82
Oil	cent/kWh	10,07
Electricity	cent/kWh	15,03
District heating	cent/kWh	9,31
Wood	cent/kWh	5,69

Figure 26: price development Peak price scenario



The energy price scenarios described reflect the assumed average price development of different energy carriers in the EU25. At the same time, considerable differences in energy prices can be found when looking into the different regions of the EU.

To take into account typical regional differences, the price scenarios were assumed to be valid for the moderate European zone. Typical and long term differences in energy prices for private consumers between the moderate European zone and the other zones have been assessed on basis of EUROSTAT data on consumer prices in the years 2000 to 2006. According to the differences found, the energy price scenarios have been adapted for each region according to the following table.

Table 4: Energy price levels in the EU

Energy price levels	EU15 northern	EU15 moderate	EU15 southern	NEW8
Coal	100%	100%	100%	100%
Oil	120%	100%	120%	100%
Gas	120%	100%	100%	70%
Biomass	80%	100%	120%	90%
Solar and other RES	100%	100%	100%	100%
Steam (district heat)	120%	100%	100%	90%
Electricity	100%	100%	70%	80%

Thereby it is assumed that the current energy price difference between regions will remain for several years in the future. The values already take into account recent developments, like the rise in gas prices in Eastern Europe.

To be able to calculate the average energy costs of heating energy saved during an assumed service life of energy saving investments of 30 years, the fuel mixes assumed in the PRIMES-scenarios [PRIMES] for the year 2015 was assumed. The corresponding fuel mixes for the different zones are described in Table 5.

Table 5: Fuel mix from EU25 Primes scenario (only for heating purposes)

Fuelmix 2015	EU15 northern	EU15 moderate	EU15 southern	NEW8
Coal	0%	0%	0%	5%
Oil	14%	19%	17%	7%
Gas	2%	55%	62%	45%
Biomass	14%	9%	10%	8%
Solar and other RES	0%	1%	1%	1%
Steam (district heat)	28%	4%	0%	24%
Electricity	42%	11%	10%	10%

For cooling appliances the use of electric systems has been assumed to be applied in most cases.

The before mentioned assumptions on price scenarios and fuel mixes lead to the following average prices:

Table 6: Resulting average energy prices 2006-2036 in cent/kWh end energy including tax

Cent/kWh	WEO reference	Peak price scenario
EU15 northern	9,62	12,03
EU15 moderate	7,80	10,61
EU15 southern	7,71	10,59
NEW8	6,40	8,33

5.3.2 INVESTMENT COSTS

The data for investment costs are taken from the previous Ecofys-studies “Cost-Effective Climate Protection in the EU Building Stock” and “Cost-Effective Climate Protection in the Building Stock of the New EU Member States - Beyond the EU Directive on the Energy Performance of Buildings”. As described in chapter 5.2 “Mechanisms of U-value optimum”, the U-value optimum has been calculated from the investment side only depending on the incremental costs per centimetre insulation.

The investments referred to include material and labour costs, per m² as well as appropriate taxes (VAT). The costs per additional centimetre can be, for example assessed by looking at the total costs of a insulation system with 10 cm and with 30 cm and dividing the difference in costs by 20 (increase in insulation thickness). The result is different from the fixed costs per m² but can be considered the same for both retrofit and in new building.

Table 7: investment costs insulation

Spec. costs [Euro/cm/m²]	EU15 northern	EU15 moderate	EU15 southern	NEW8 (Eastern EU)
External wall	1,88	1,25	1,25	1,00
Roof	1,20	0,80	0,80	0,80
Floor	1,50	1,00	1,00	0,80

To calculate the annual costs based on the investments described, an interest rate of 4% (Eastern Europe: 6%) has been assumed.

5.4 RESULTS

In the following graphs, the life cycle costs are presented as examples for 3 cities (Stockholm, Amsterdam and Seville) in 3 climatic zones, based on the price scenario “WEO reference”.

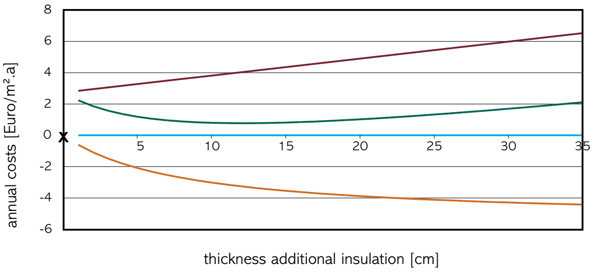
Whether or not it is feasible to start to apply additional insulation depends on the fixed costs per m², the starting point regarding U-value and the costs of saved energy. For example coupled retrofit actions on external walls in Stockholm, with the given inputs are not cost efficient (annual overall costs always above zero) because of the higher investment costs and the good U-value (0,5 W/m²K) at the starting point for the calculations. This looks different from the case of a new building in Stockholm or from the examples situations in Amsterdam and Seville (curves for annual overall costs have a minimum below zero).

On the other hand, the optimum U-value only depends on investment costs for the additional centimetres of insulation and corresponding energy-cost-savings. This effect makes the U-value recommendations robust against differing starting points of U-value and fixed costs per m².

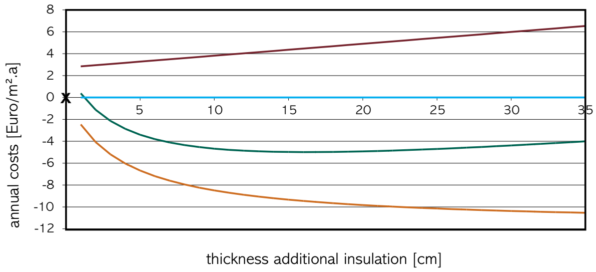
Figure 27: Cost efficiency insulation of external walls retrofit and new, price scenario "WEO reference"

Stockholm

Cost analysis external wall insulation retrofit, per m²

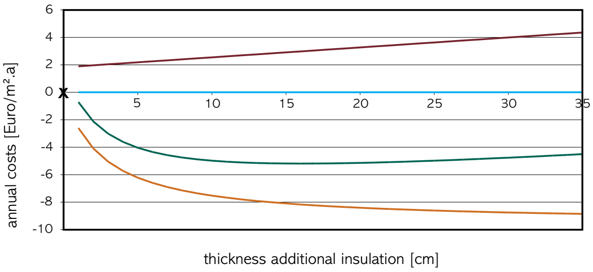


Cost analysis external wall insulation new, per m²

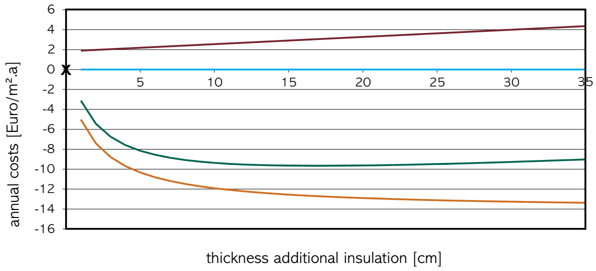


Amsterdam

Cost analysis external wall insulation retrofit, per m²

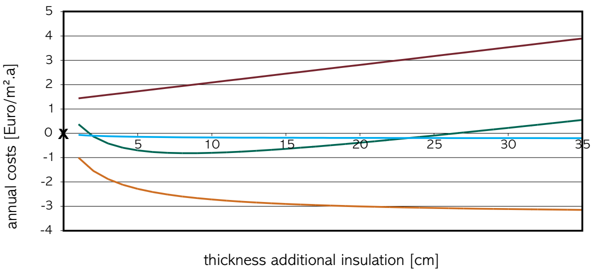


Cost analysis external wall insulation new, per m²

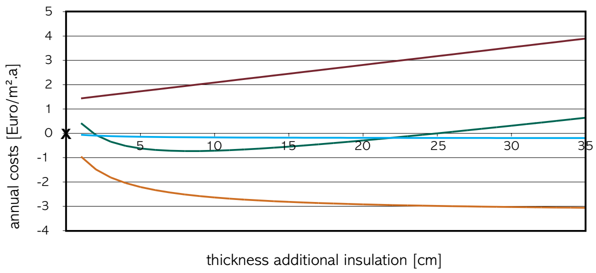


Seville

Cost analysis external wall insulation retrofit, per m²



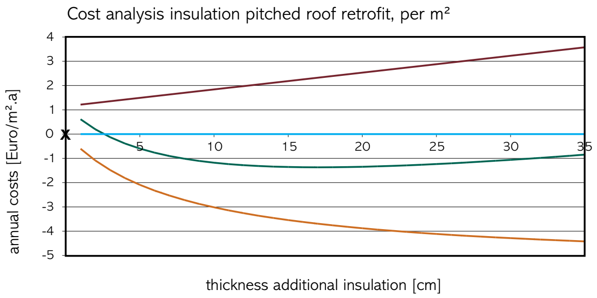
Cost analysis external wall insulation new, per m²

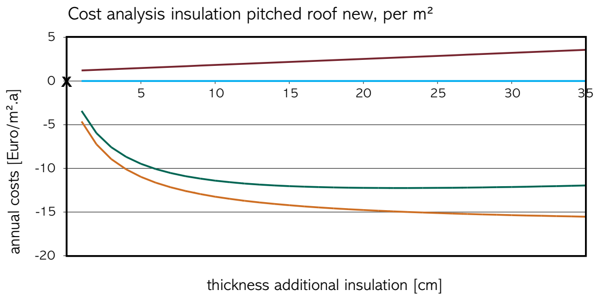


annual capital costs — energy cost savings cooling — annual overall costs — energy cost savings heating

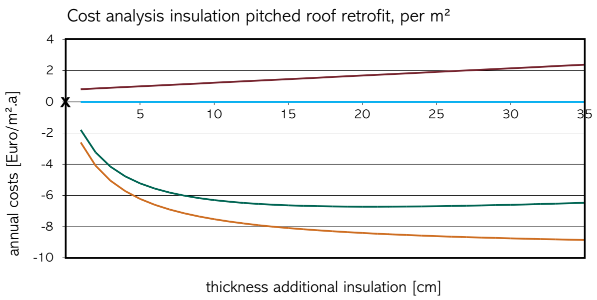
Figure 28: Cost efficiency insulation of roofs retrofit and new, price scenario WEO reference

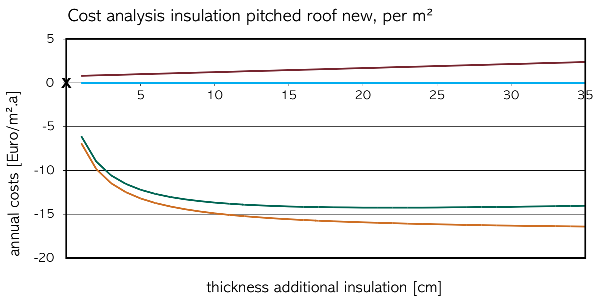
Stockholm



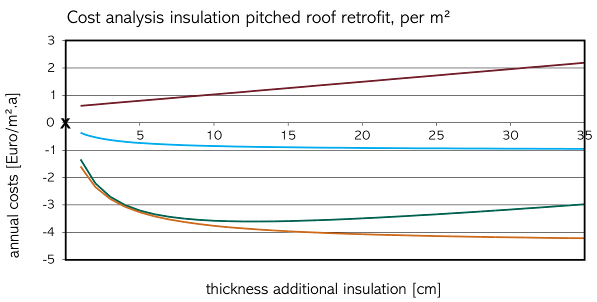


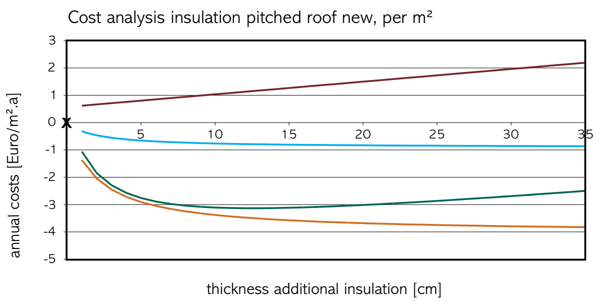
Amsterdam





Seville

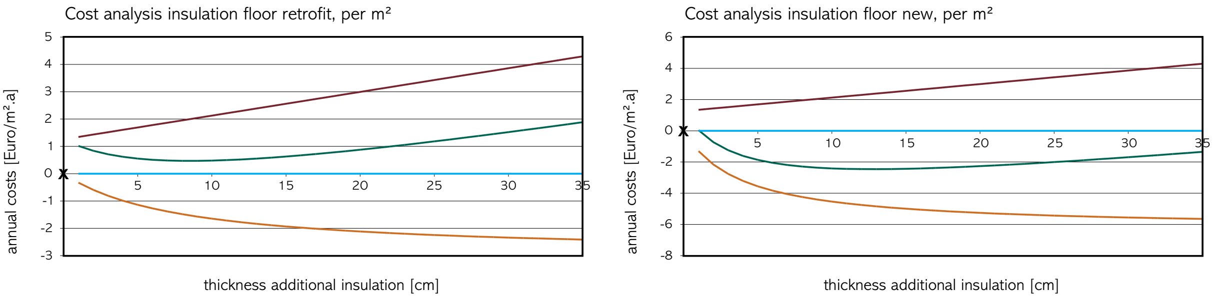




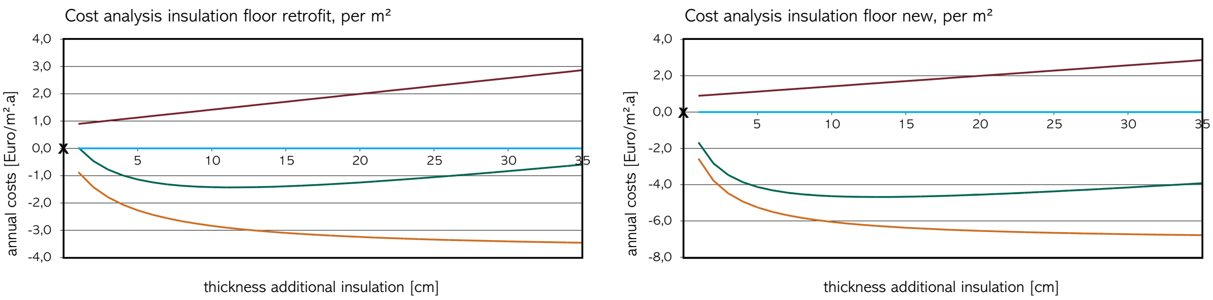
annual capital costs — energy cost savings cooling — annual overall costs — energy cost savings heating

Figure 29: Cost efficiency insulation of floors retrofit and new, price scenario WEO reference

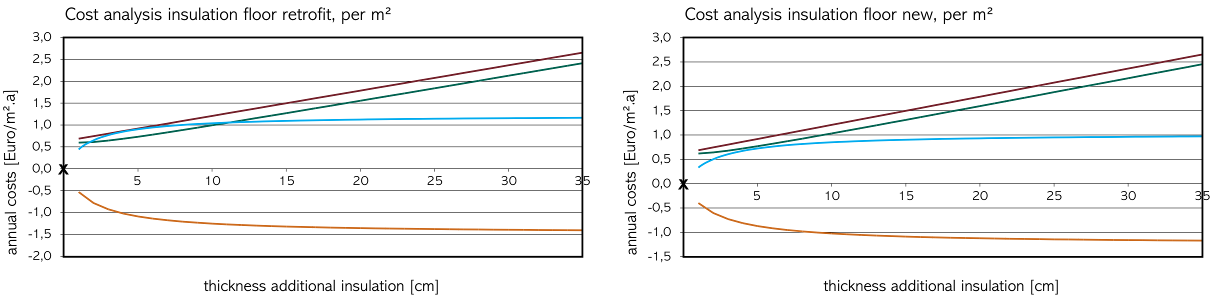
Stockholm



Amsterdam



Seville



annual capital costs — energy cost savings cooling — annual overall costs — energy cost savings heating

As with the results of previous Ecofys-studies, insulation measures are in most cases cost efficient, with the exception of retrofit of walls and floors in northern Europe and floor insulation in southern Europe. Therefore in the following calculations, the optimum U-value is described assuming insulation measures are applied (equal to the minimum in the cost curve beyond the starting point). In parallel to the findings in chapter 4 the effect of taking cooling energy into account becomes clear in the example of southern Europe (Seville) and results in more ambitious values for facades and roofs and less ambitious values for floors. In the following graphs, the starting points and optimum U-values based on cost efficiency are described. Starting point for new buildings is no insulation, for retrofit see Table 8.

Figure 30: Starting points and optimum cost efficiency Stockholm, scenario WEO reference

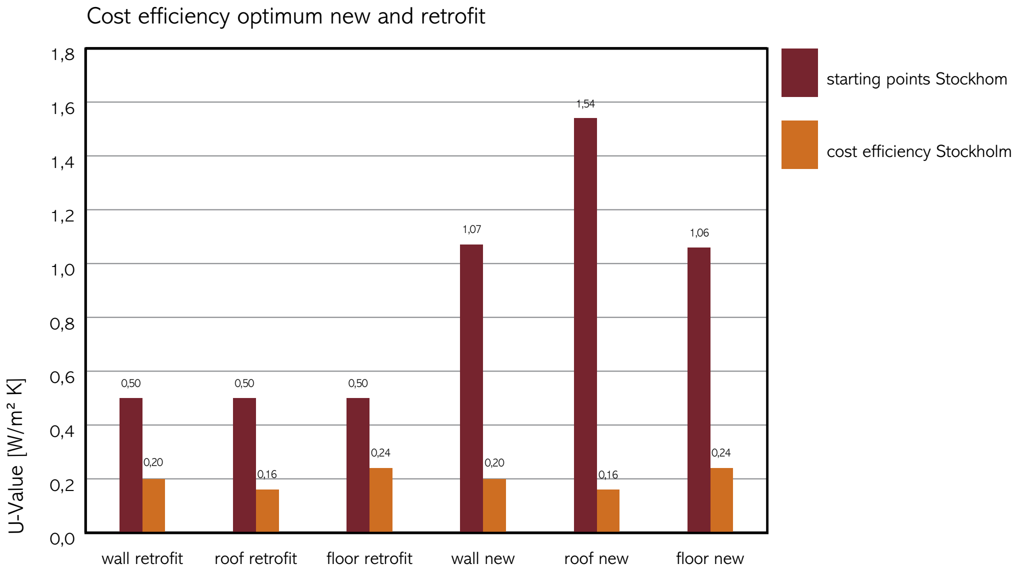


Figure 31: Starting points and optimum cost efficiency Amsterdam, WEO reference

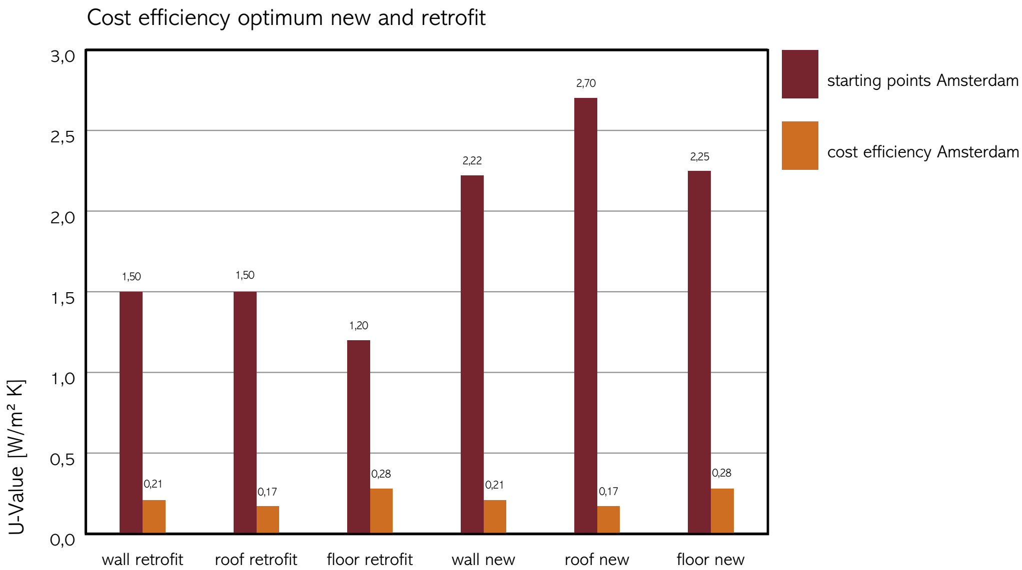
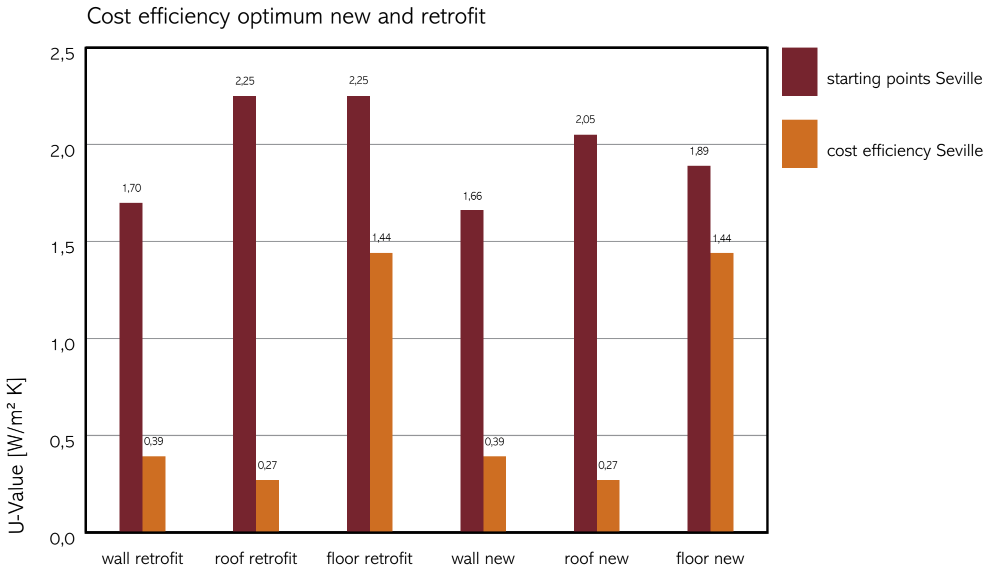


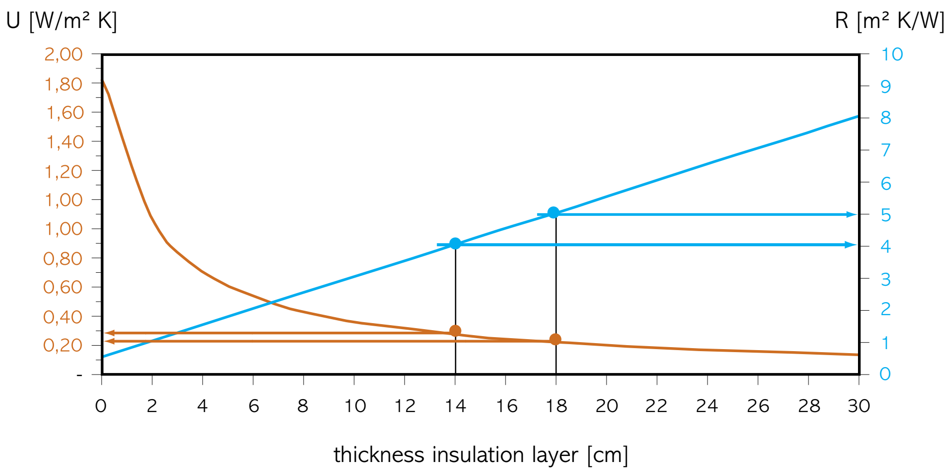
Figure 32: Starting points and optimum cost efficiency Seville, WEO reference



The optimum U-value, if insulation is applied, is the same in retrofit and new buildings, see Chapter 5.2. In the following, graph only one value is displayed in the tables and graphs this being applicable to both retrofit actions and new buildings.

From the R-value point of view the graph shows the relationship between centimetres of insulation added and the corresponding U- and R-value for a wall construction.

Figure 33: Centimetres of insulation, U-value and R-value



The following graphs show the results of this life cycle cost curves in respect to their financial optimum for the assessed 100 cities, grouped according to heating degree days. The detailed data per city can also be found in Annex 2.

Figure 34: Recommended U-values cost efficiency for walls, WEO reference

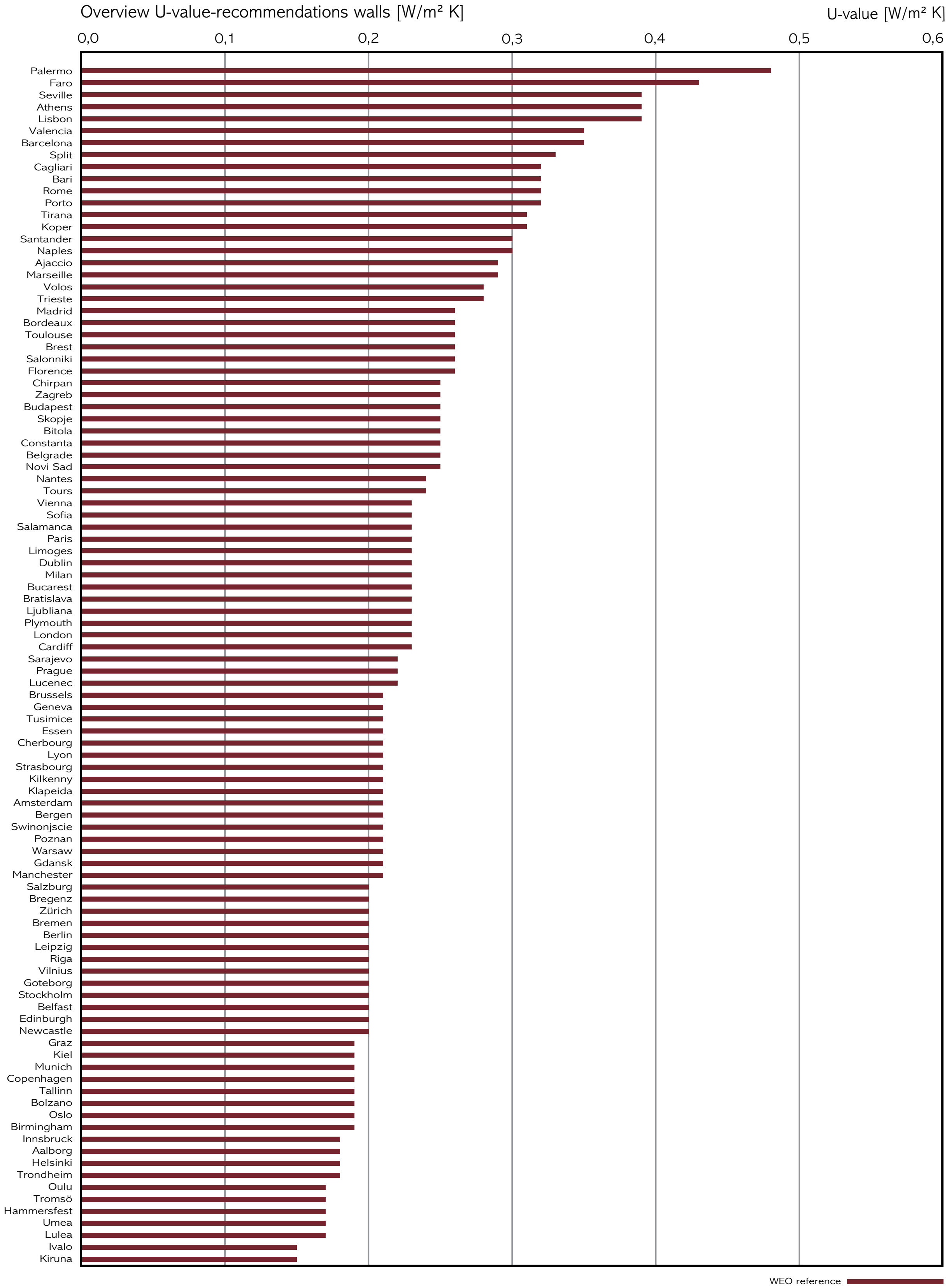


Figure 35: Recommended U-values cost efficiency for roofs, WEO reference

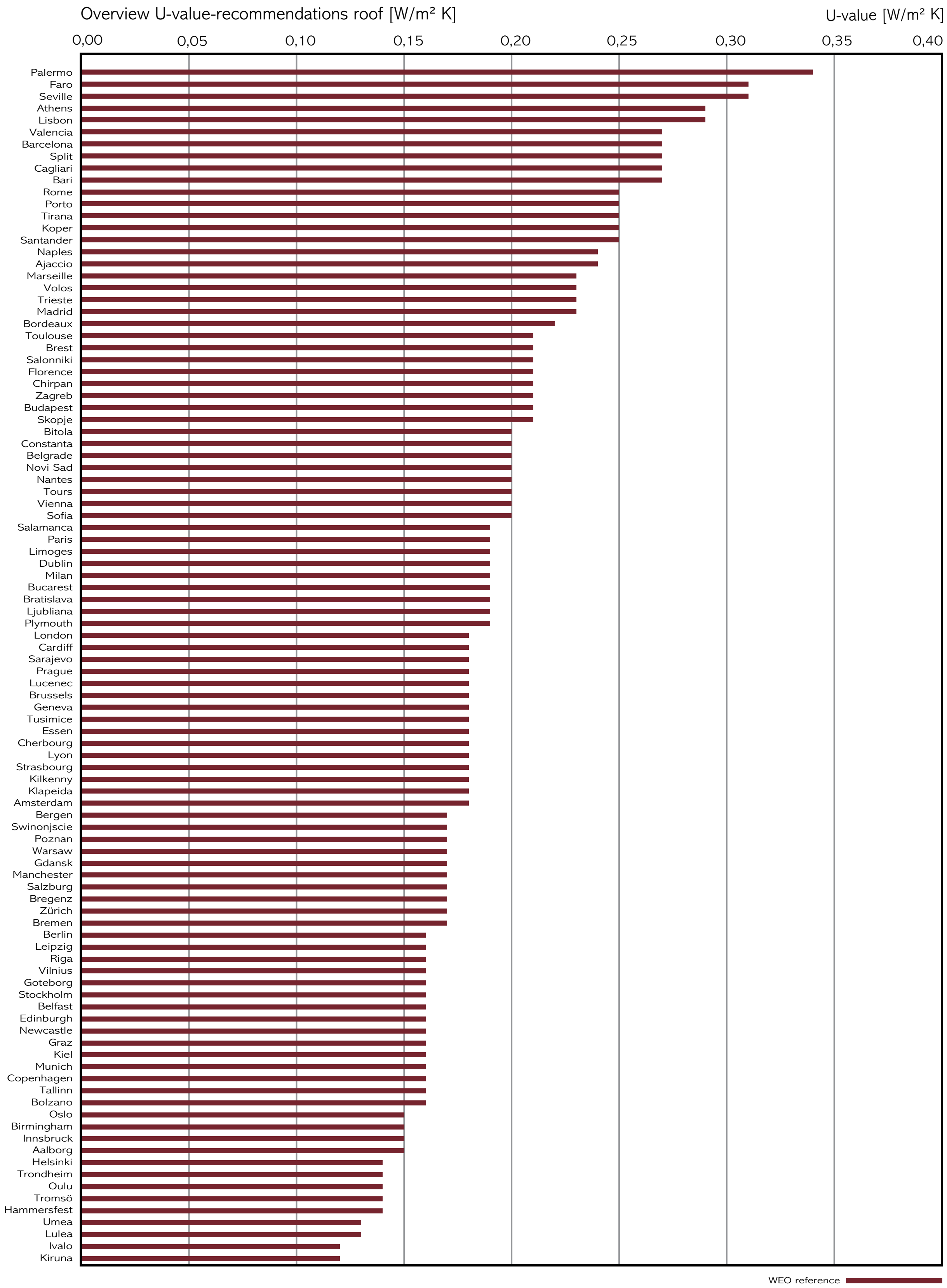
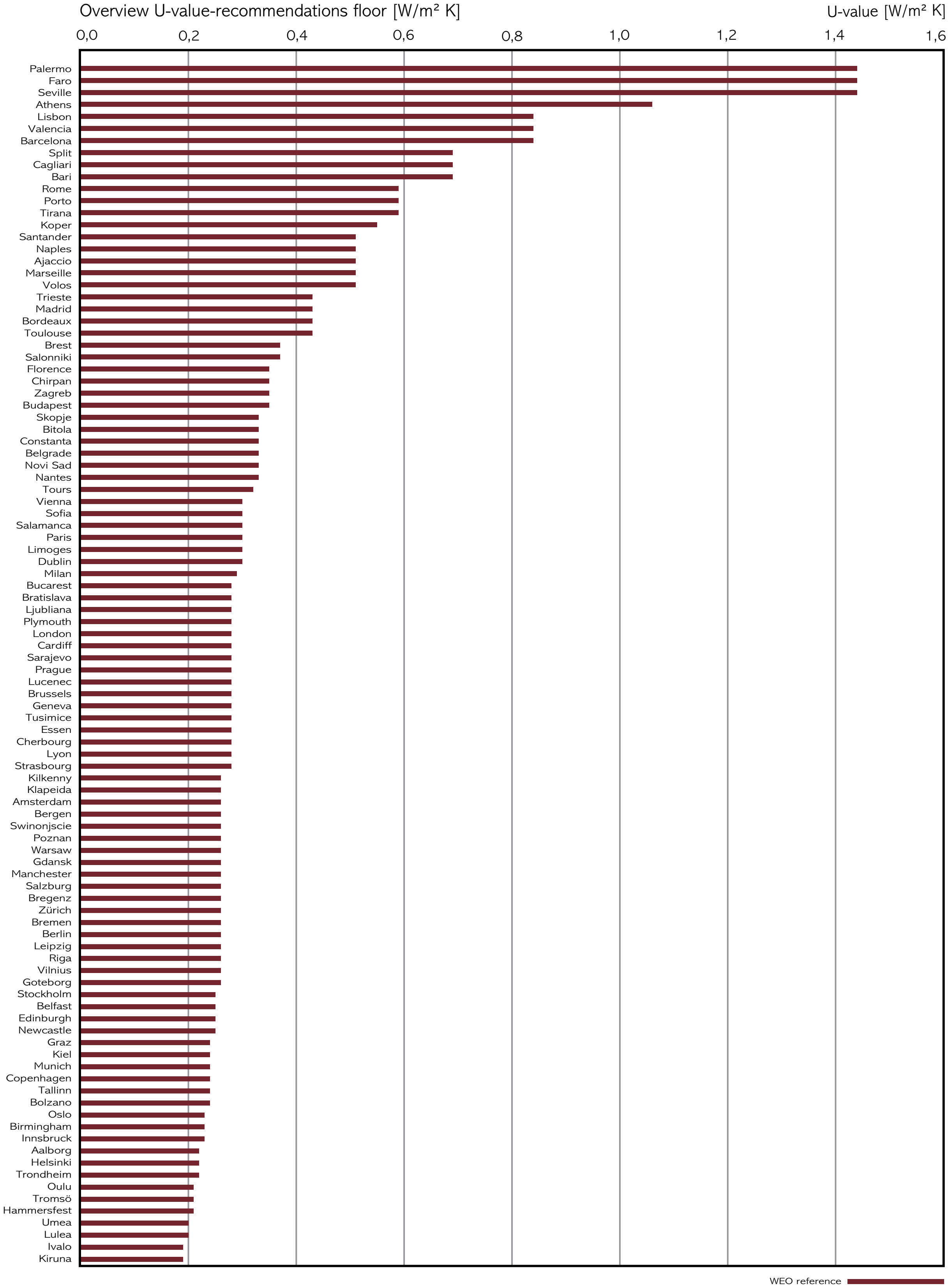


Figure 36: Recommended U-values cost efficiency for floors, WEO reference



From the data above, U-value maps can be derived, see Annex 5. For an overview of results per city, see Annex 2.

6] U-VALUES ACCORDING TO CLIMATE PROTECTION TARGETS

6.1 BACKGROUND

The objective of the United Nation Framework Convention on Climate Change (UNFCCC) is to stabilise greenhouse gas concentrations to avoid dangerous anthropogenic interference with the climate system. This target is formulated in Article 2 of the UNFCCC [UNFCCC 1992], which is accepted by nearly all countries in the world.

Several countries, including the European Union (EU), and many environmental non-governmental organisations have agreed that global average temperature increase should be limited to 2°C above pre-industrial levels to avoid such dangerous interference. As early as 1996, the Council of Ministers of the EU agreed that "global average temperatures should not exceed 2 degrees Celsius above pre-industrial level and that therefore concentration levels lower than 550 ppm CO2 should guide global limitation and reduction efforts" [EU Council 1996]. The target of 2°C has been reaffirmed subsequently as the EU's submissions to the international negotiation processes in 2006 ([UNFCCC 2006a, 2006b]). The EU states that it "will require global greenhouse gas emissions to peak within the next two decades, followed by substantial reductions in the order of at least 15% and perhaps by as much as 50% by 2050 compared to 1990 levels."

The reduction of global emissions by 2050 will have to be achieved differentiated between countries based on their different responsibilities for climate change and different mitigation capabilities. Developed countries that have contributed most to historical emissions will have to reduce emissions substantially. Developing countries may increase emissions for a defined period and would later also reduce emissions. Accordingly, industrialised countries' will have to reduce emission by -70% to -90% in 2050 compared to their 1990 emissions to meet the 2°C target ([den Elzen and Meinshausen 2005]; [Höhne et al. 2005]).

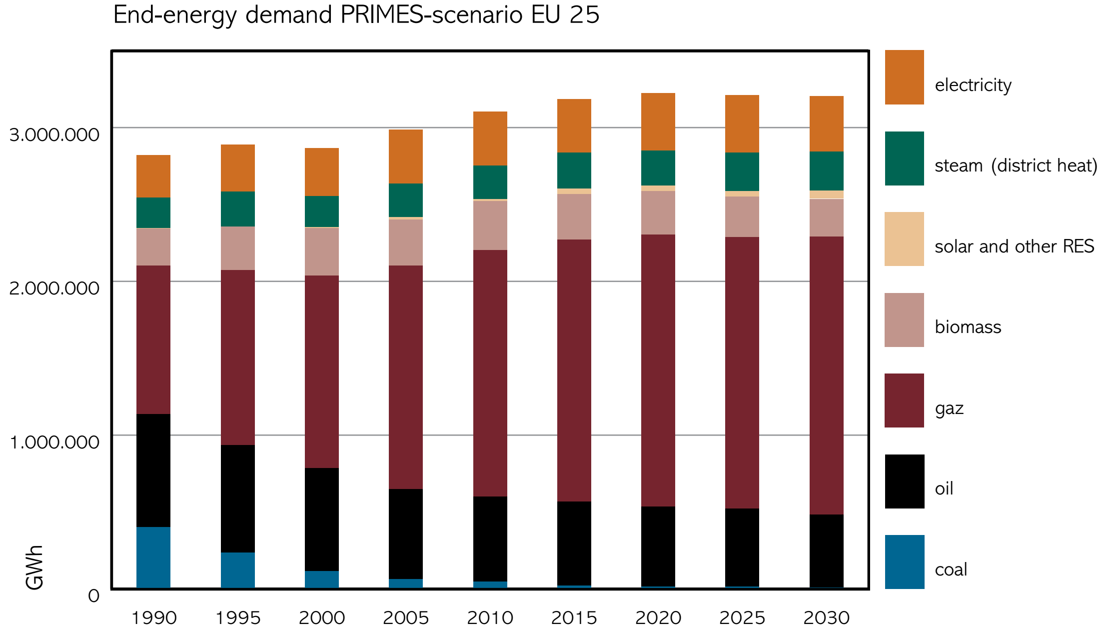
It is likely that emissions in the building sector will have to be reduced more than the average over all sectors. Emission reduction costs and capabilities differ among sectors. The International Panel on Climate Change (IPCC) is the most important scientific advisory body to the UNFCCC. Its third assessment report [IPCC 2001] identified emission reduction costs until 2020. For many developed countries these costs were estimated to be up to 200 US $ per ton of carbon avoided for a number of sectors, e.g. transport, energy supply and agriculture. Especially for the building sector estimated emission reduction costs are mainly negative which means that they can save up to 400 US $ per ton of carbon avoided until 2020 [IPCC 2001]. The cost effectiveness of the CO2 mitigation measures in the building stock were confirmed in several reports ([Ecofys 2004], [Ecofys 2005]). The high reduction potentials and the cost efficient reduction measures require the building sector to realise an emission reduction share above average compared to the other sectors. Assuming that the target for the industrial countries should be 80% and taking into account that the EU-building stock will further increase in the next years, it is assumed that the building sector has to contribute with 85% CO2-emission-savings until 2050 referred to 1990.

At the same time, the foreseen development of the fuel mix for space heating purposes (for example switching from coal and oil to gas and increasing the share of biomass and other renewables, see Figure 37) and the increase in system efficiency compared to 1990 (e.g. condensing boilers) will result in an improvement of the CO2-emission factor for households of about 19%. This leads to an average of 82% to be saved on energy demand for space heating.[7]

[7] The assumed improvement of the CO2 emission factor results in a relatively small change of the saving target from 85% to 82%. This is caused by the application of the improved emission factor on a high overall saving objective. Mathematically it results from following calculation:
1 - (1-85%)/(1-18.8%) = 81,53%

The fuel mix according to the PRIMES-scenario is shown in the graph below.

Figure 37: Fuel mix development PRIMES-scenario for EU25



6.2 METHODOLOGY

The energy demand of a reference building in 1990 was used as a baseline in order to calculate the required insulation standards to reach the energy savings described in the Post-Kyoto targets. An insulation standard corresponding to possible Post-Kyoto targets for 2050 is then defined by the necessary energy saving measures to reach the target energy and corresponding CO_2-savings compared to the reference situation. The European building stock in 1990 was dominated (and still is) by single family houses built before 1975 that have not been renovated yet. This type of buildings has therefore been chosen as the reference situation.

As in 1990 also buildings with already less energy demand existed (buildings built between 1975 and 1990 and buildings that have been already renovated at that time) the U-values to meet possible Post-Kyoto targets could also be a bit more ambitious. However this small effect is by far dominated by the final decision on CO_2-saving targets until 2050, which easily can lead to a factor 2 in ambition concerning energy demand of buildings, as described in the sensitivity analysis of chapter 6.4. As a consequence, the calculated values for possible Post-Kyoto targets can only be a rough estimate which still give a good indication concerning the position of the calculated financial optimum of U-value in relation to climate protection targets.

The specification of the reference single family house (as also used in chapter 4 ”Insulation and cooling”) and the qualities assumed for the building envelope have been taken from the Ecofys reports II to V. The insulation levels and corresponding energy demand per m² and year are described in the following table.

Table 8: Baseline assumptions for savings according to Post-Kyoto targets

	Zones			
Single family house built before 1975	northern	moderate	southern	eastern
U-value floor	0,50	1,20	2,25	1,22
U-value wall	0,50	1,50	1,70	1,29
U-value roof	0,50	1,50	2,25	1,08
U-value window	3,00	3,50	4,20	4,20
resulting energy demand [kWh/m² a]	160	264	151	265

Houses built before 1975 have usually not been insulated. The U-values described are therefore only dependant on the average building materials and techniques used for floors, external walls and roofs used at that time.

To assess the insulation standard necessary to meet the Post-Kyoto targets, the energy demand of the reference buildings was compared to buildings with a set of applied energy saving measures with the aim to reach the desired energy savings compared to the reference situation.

To define the packages of measures to reach the desired energy savings several measures were combined taking into account:

- a reasonable balance between insulation measures, improvement of windows and the use of ventilation systems with heat recovery
- increasing insulation level from floor insulation via wall insulation to roof insulation

By using these principles, the packages of measures with the desired energy performances (82% savings compared to the baseline) were defined in an iterative process of calculating the results for increasingly ambitious packages.

The calculations were carried out in accordance with the principles of the European Norm EN 832, as applied in the Ecofys reports II to VI. The Post-Kyoto targets were thereby assumed to be the same for the 4 assessed zones.

6.3 RESULTS

Table 9 shows the maximum U-values based on a Post-Kyoto target of 85% CO_2-emission-savings for the building stock. It should be borne in mind that the savings target can also be reached by other combinations of measures, e.g. including ventilation with heat recovery (VHR, given with the respective system-efficiency) in other climate zones than northern Europe or putting a different emphasis on improved windows.

Table 9: Measures to reach Post-Kyoto targets (85% CO_2-emission savings)

Measures to reach CO_2-emission-savings of 85%	Zones			
	northern	moderate	southern	eastern
U-value floor	0,25	0,30	0,80	0,25
U-value wall	0,20	0,22	0,50	0,20
U-value roof	0,15	0,18	0,35	0,18
U-value window	1,1	1,2	1,6	1,0
VHR (efficiency in %)	80%	-	-	-
resulting energy demand [kWh/m² a]	28	48	27	49

Taking into account the retrofit cycles of 30 to 40 years, this means that from the year 2010 or the latest 2020 onward, all new houses and retrofit actions have to be carried out with the ambition to have the total building stock in 2050 on the targeted level.

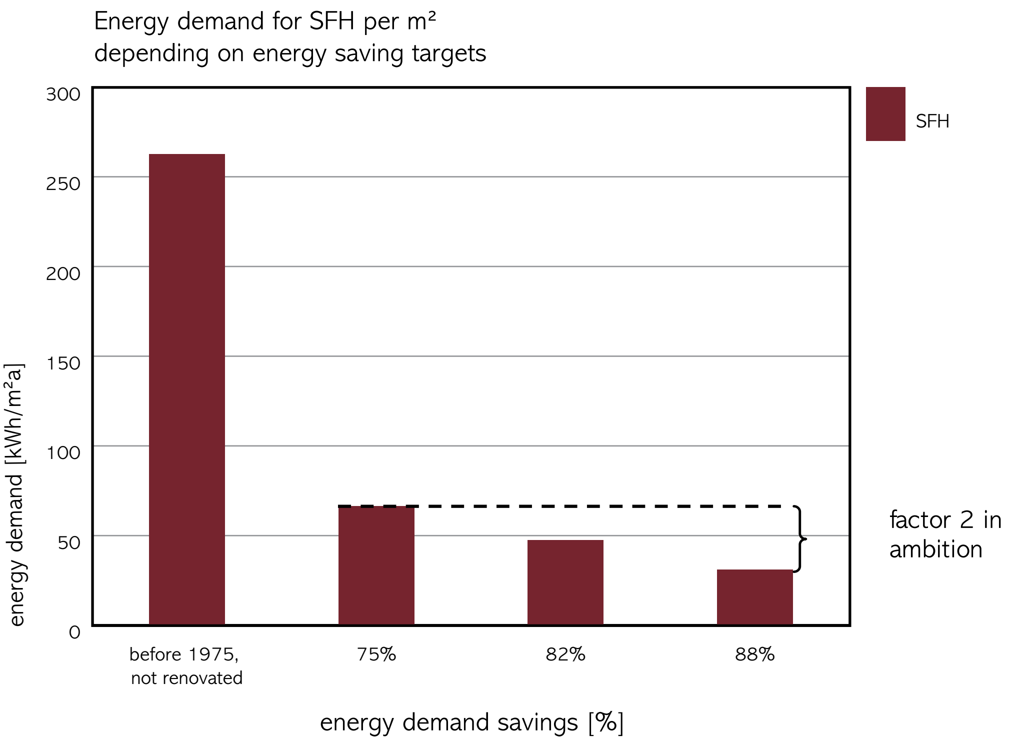
However these targeted U-values represent a theoretical average for the total building stock in 2050. One can imagine that these results will be achievable through fundamental improvement of the energy performance of the existing building stock and new constructions performing even better than above targets, in the next decades.

6.4 SENSITIVITY ANALYSIS POST-KYOTO TARGETS

Due to the fact that negotiations on Post-Kyoto targets have just started, a sensitivity analysis was carried out for the targets of 80% and 90% of CO_2-emission-savings to be realised by the building stock. If improvements of energy efficiency of systems and changes in fuel mix are taken into account, the energy demand has to be decreased by 75% to reach 80% of CO_2-savings and 88% to reach 90% savings in CO_2-emissions. The corresponding possible energy efficiency packages to reach these targets are described below.

However, the decision on saving 80% or 90% of CO_2-emissions (respective 75% or 88% of energy demand) leads to a factor 2 in ambition concerning the targeted energy standard of a building as described in the following graph.

Figure 38: Energy demand for SFH (moderate zone) depending on different energy saving targets



Corresponding possible energy efficiency packages to reach these targets are described below.

Table 10: Measures to reach Post-Kyoto targets (80% CO_2-emission savings)

Measures to reach CO_2-emission-savings of 80%	Zones			
	northern	moderate	southern	eastern
U-value floor	0,30	0,45	1,00	0,40
U-value wall	0,28	0,35	0,65	0,30
U-value roof	0,20	0,25	0,50	0,20
U-value window	1,1	1,2	1,6	1,2
VHR (efficiency in %)	80%	-	-	-
resulting energy demand [kWh/m² a]	40	65	38	67

Compared to the solutions necessary to reach the 85% CO_2 emission savings, the targeted U-values for floor, façade and roof to reach 80% savings could be less ambitious, providing the quality of windows is kept at the same level.

Table 11: Measures to reach Post-Kyoto targets (90% CO2-emission savings)

Measures to reach CO_2-emission-savings of 90%	Zones			
	northern	moderate	southern	eastern
U-value floor	0,20	0,20	0,60	0,25
U-value wall	0,15	0,13	0,40	0,20
U-value roof	0,12	0,10	0,30	0,18
U-value window	1,0	1,0	1,2	1,0
VHR (efficiency in %)	80%	-	-	50%
resulting energy demand [kWh/m² a]	19	33	19	30

To reach CO_2-emissions savings of 90%, substantial improvements compared to the 85%-savings scenario are necessary for target U-values, the quality of windows and integration of ventilation systems with heat recovery. An overview of the targeted U-values depending on the ambition of possible Post-Kyoto targets is shown in the following graphs.

Figure 39: U-values for floors according to different Post-Kyoto targets

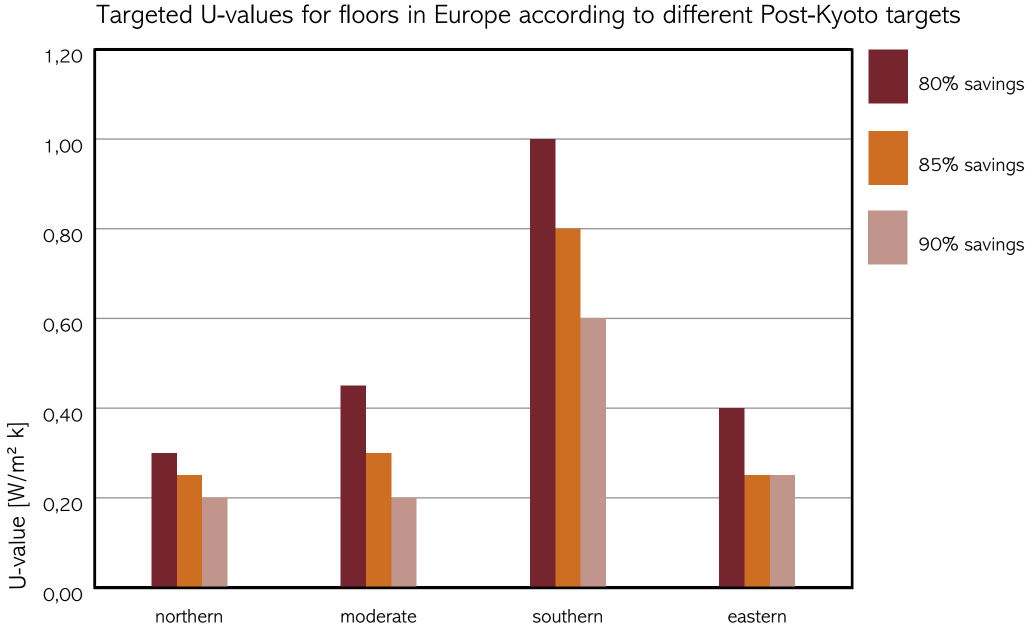


Figure 40: U-values for walls according to different Post-Kyoto targets

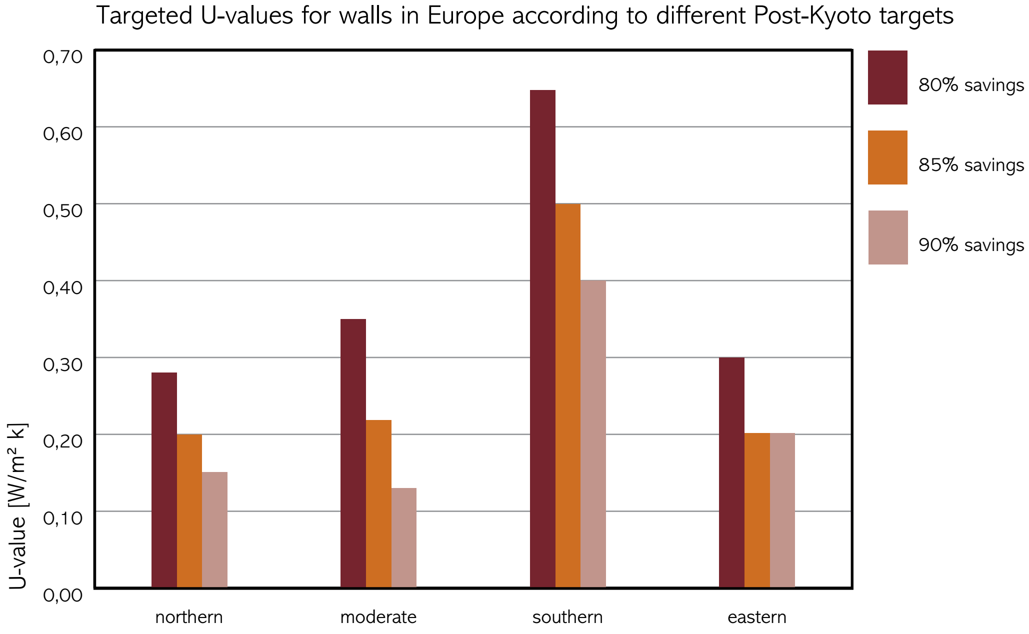
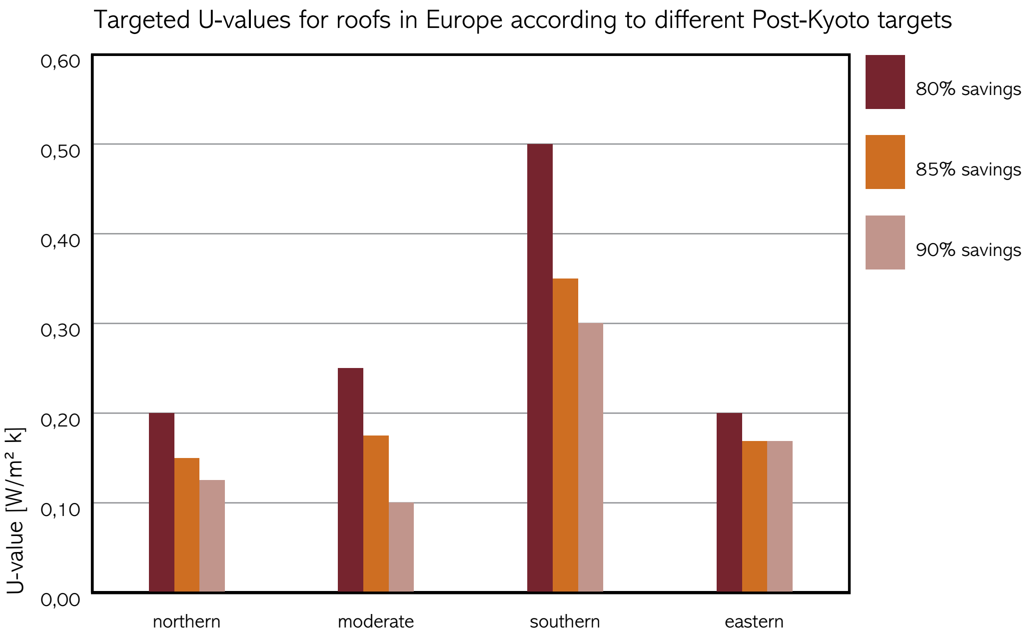


Figure 41: U-values for roofs according to different Post-Kyoto targets



7] OVERVIEW RESULTS COST EFFICIENCY AND CLIMATE PROTECTION

The following 4 graphs show a comparison of the results of the cost-efficiency calculations compared to possible Post-Kyoto targets (85% savings). The cities Stockholm, Amsterdam, Seville and Warsaw were the assessed regions.

Figure 42: Results cost efficiency and Post-Kyoto (85% savings) for Stockholm

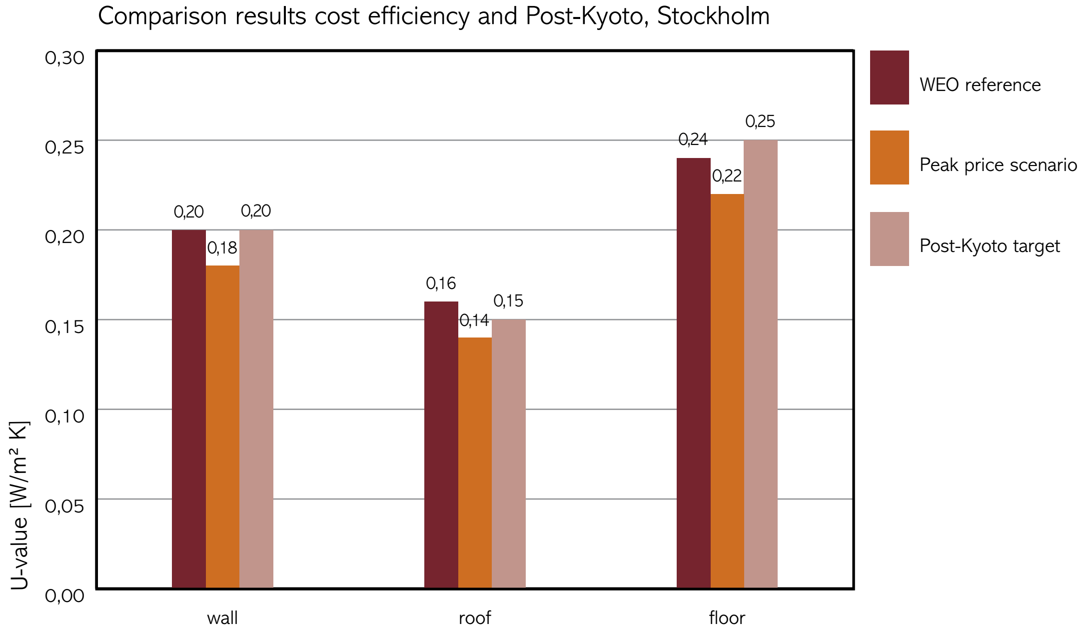


Figure 43: Results cost efficiency and Post-Kyoto (85% savings) for Amsterdam

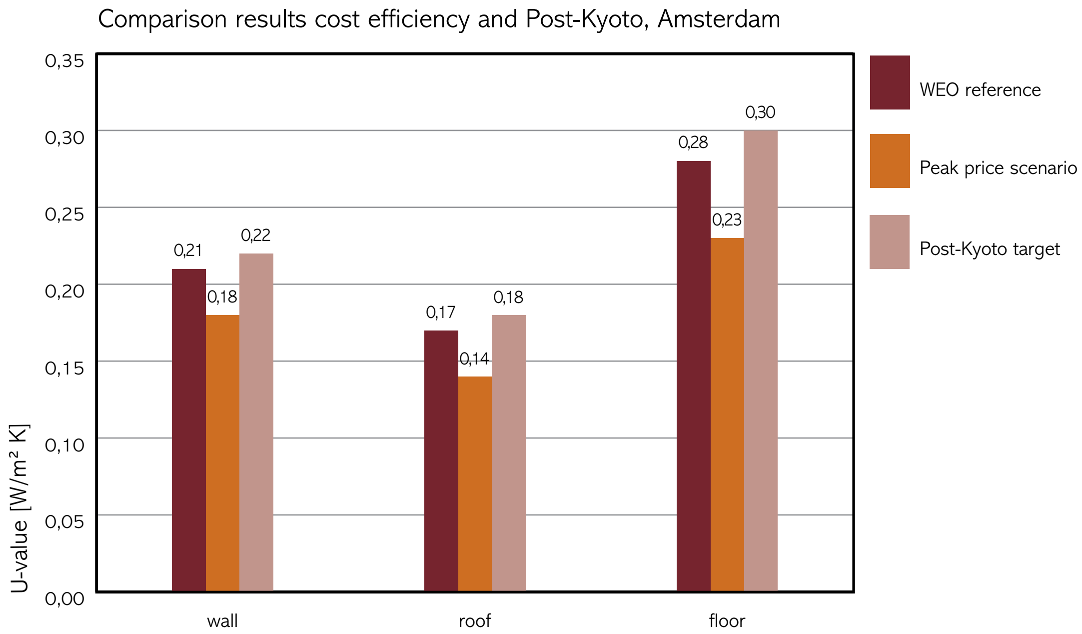


Figure 44: Results cost efficiency and Post-Kyoto (85% savings) for Seville

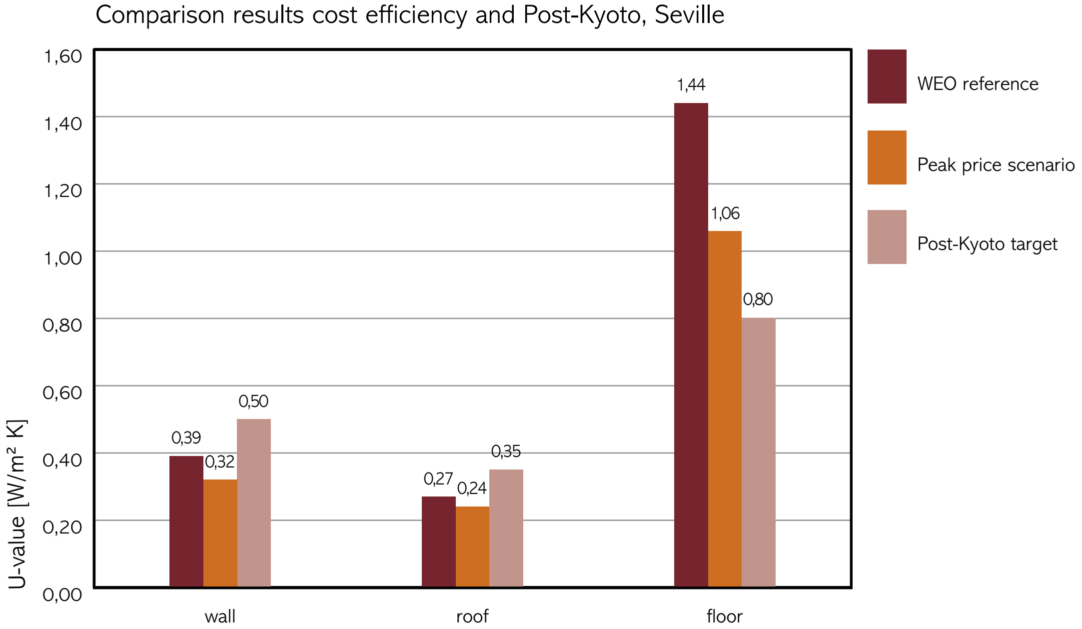
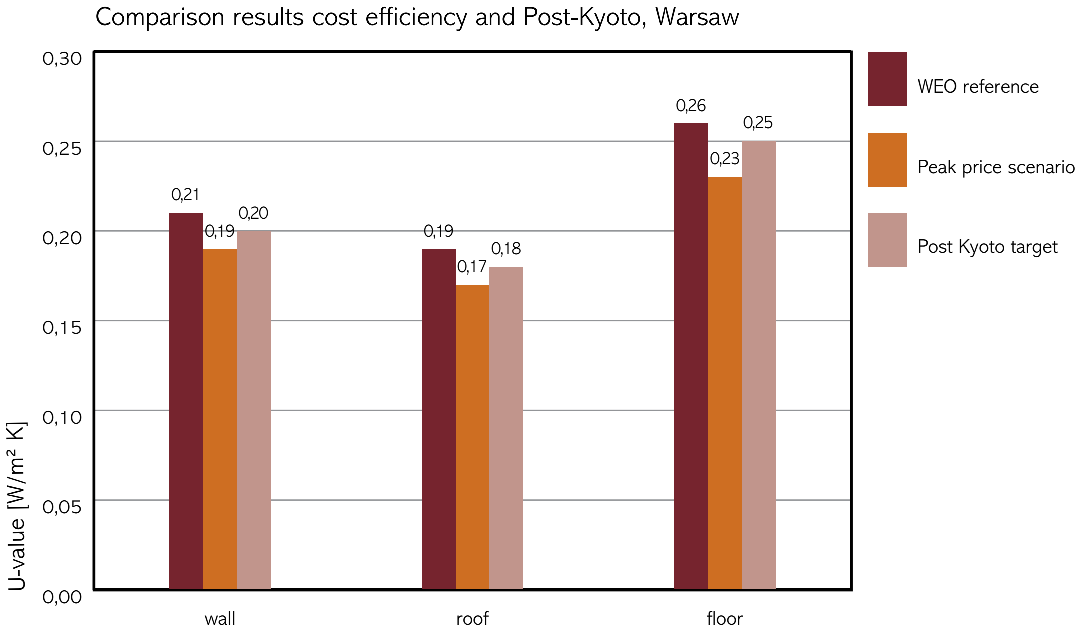


Figure 45: Results cost efficiency and Post-Kyoto (85% savings) for Warsaw



In general, the recommendations based on cost-efficiency are similar to the recommendations derived from possible Post-Kyoto targets. If adapted, the findings on floor insulation and cooling demand, could also account for floors in southern Europe, which show larger differences in this comparison.

As an important conclusion it can be stated that the climate targets discussed and the corresponding insulation levels necessary can be justified from a financial point of view.

8] COMPARISON OF RESULTS

The results of the calculations for U-value from an economic point of view and from the viewpoint of possible Post-Kyoto targets are compared hereinafter with existing requirements in the assessed countries. This can be done in two ways.

The first way is to directly compare the U-value from above calculations with legal requirements on component level. This comparison is done in chapter 8.1.

In a second approach, the calculated U-value are used as input for national calculation schemes to meet the required standards on the overall energy performance of a building according to the EPBD. According comparisons are described in chapter 8.2.

8.1 COST-EFFICIENT U-VALUES VERSUS REQUIRED U-VALUES

In combining the results of the calculations with the required U-values the following figures can be drawn. The figures may visualise the gap between the existing minimum requirements and what on the basis of today's (May - September 2007) energy prices and environmental targets should be recommended. For a detailed overview on the specified values for national regulations for component requirements and the according results from the cost-efficiency calculations please see information from [EURIMA 2007] in Annex 3.

Figure 46: Existing and recommended U-values on the basis of cost efficiency (WEO 2006 energy prices scenario) and CO_2 climate targets for wall constructions

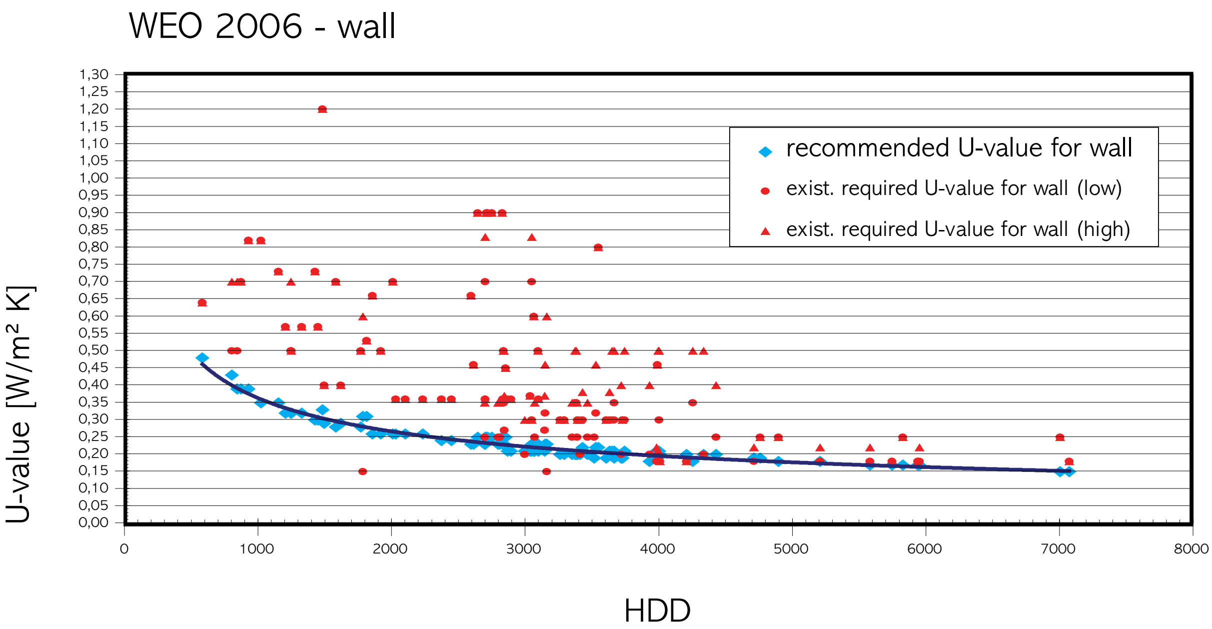


Figure 47: Existing and recommended U-values on the basis of cost efficiency (Peak price energy scenario) and CO_2 climate targets for wall constructions

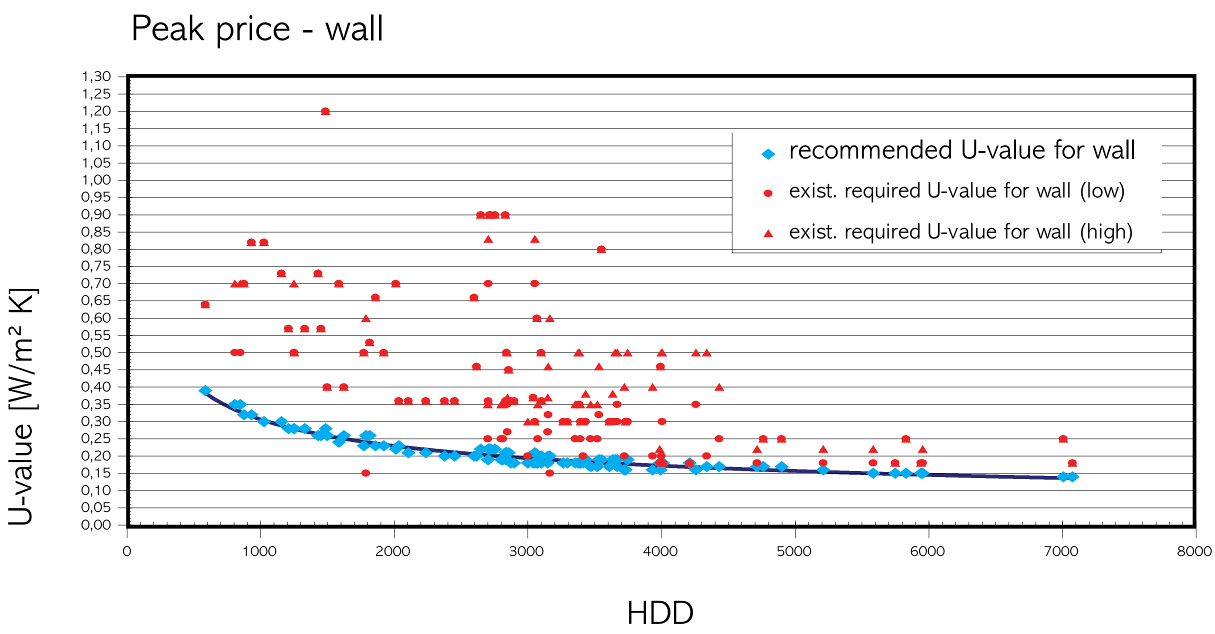


Figure 48: Existing and recommended U-values on the basis of cost efficiency (WEO 2006 energy prices scenario) and CO_2 climate targets for roof constructions

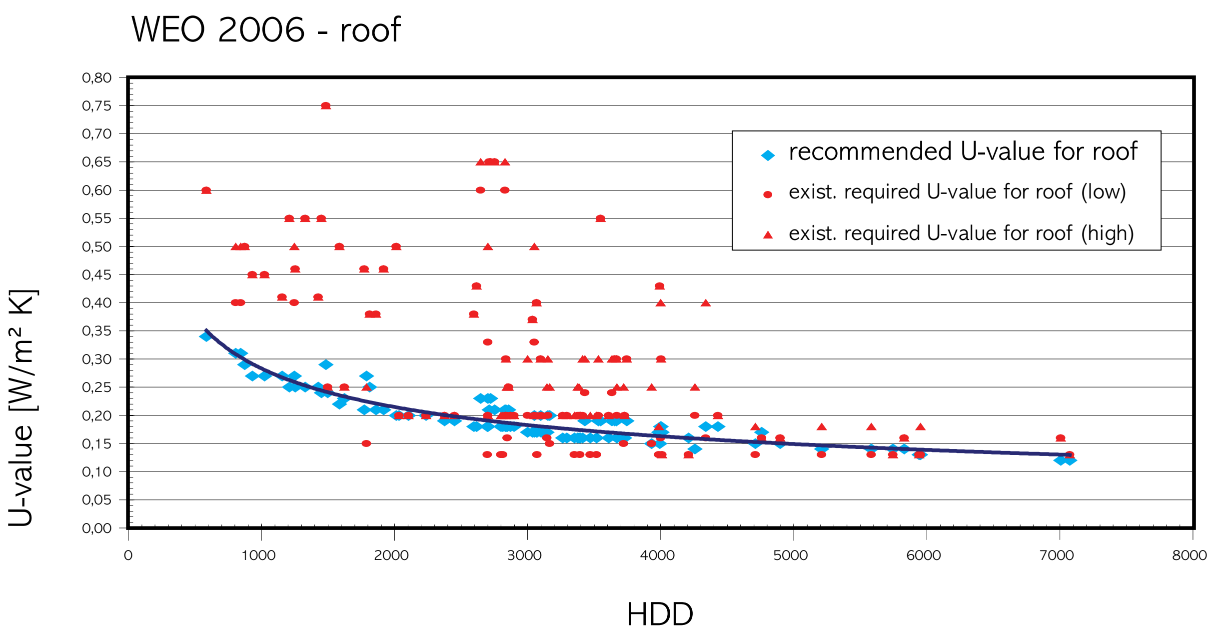


Figure 49: Existing and recommended U-values on the basis of cost efficiency (Peak price energy scenario) and CO_2 climate targets for roof constructions

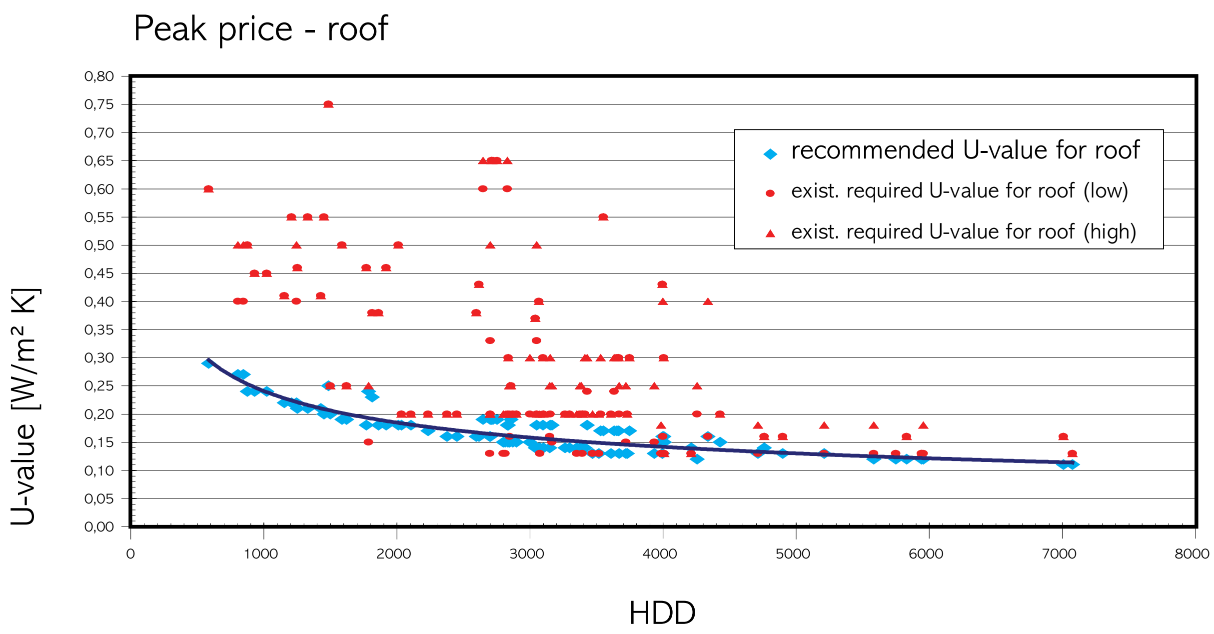


Figure 50: Existing and recommended U-values on the basis of cost efficiency (WEO 2006 energy prices scenario) and CO_2 climate targets for floor constructions

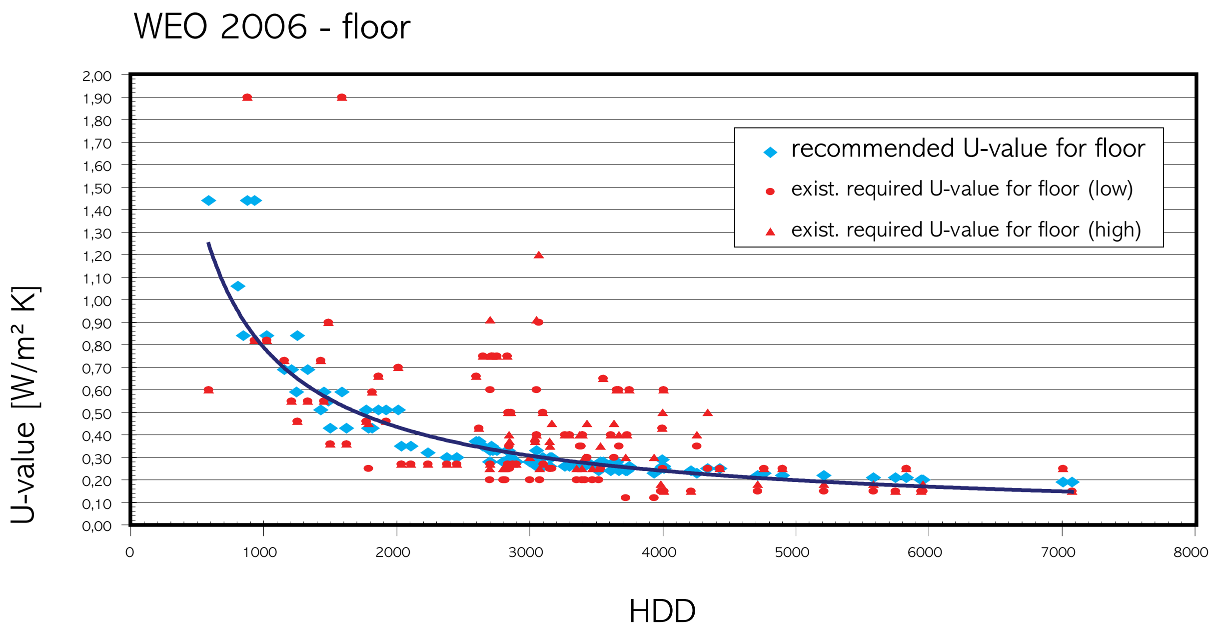
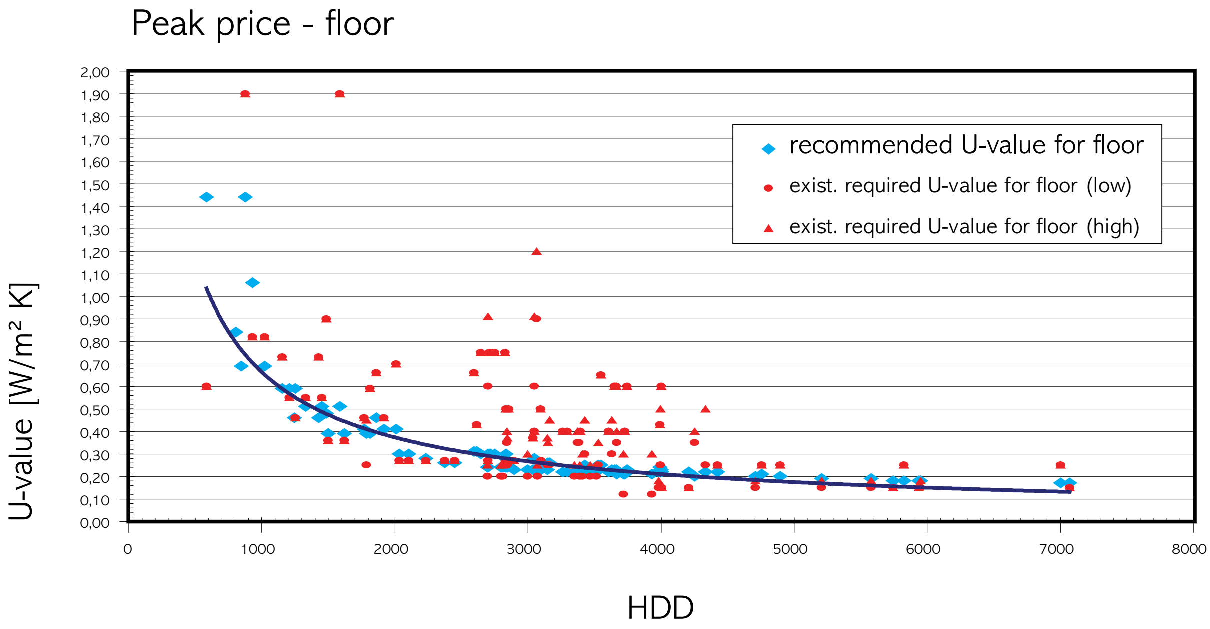


Figure 51: Existing and recommended U-values on the basis of cost efficiency (Peak price scenario) and CO_2 climate targets for floor constructions



The calculated results for price scenario "WEO reference" are in most cases more ambitious than current national standards.

Exceptions are floors in Finland and the UK (where in both cases the 3-step-development floor – wall – roof in insulation thickness seem to be not reflected) and (due to cooling issues taken into account in this study) floors in southern parts of Spain and Greece.

However, concerning floor insulation further restrictions could be given to meet demands like the acoustical comfort (contact noise) and building physics (level of surface temperature to avoid condensation or shorter response time of floor heating etc.) that might require more insulation (a lower U-value) for floors. As the analyses in this study is based solely on either economical or environmental (Post-Kyoto-targets) aspects of energy savings from insulation measures such design criteria were not taken into account.

Annex 5 gives a visual representation on European maps showing the difference between indicative existing requirements per country and optimum U-values as calculated for WEO 2006 and Peak price scenarios.

8.2 VERIFICATION OF RESULTS IN AN EPBD CONTEXT

The Energy Performance Buildings Directive defines that an over all energy assessment for the building should be made. Next to that on a national or regional level requirements or recommendations are given to meet minimum thermal performances on a component level.

For verification purposes the calculated optimum U-values for a few cities/countries were given as input in the national calculation schemes following the CEN standards and methodology addressed in the EPBD assuming commonly used energy supply (e. g. heating system) and energy saving measures and provisions (windows, air tightness, ventilation, lighting, etc.).

The conclusions of these calculations are described in the next page. For a full overview of data inputs and calculations, please refer to Annex 4.

Sweden

In the new Swedish building code from 2006 there are two requirements concerning energy efficiency.

1. The maximum energy use (excluding household electricity) of a house must not exceed 110 kWh/m^2 per year in the southern half of Sweden, where Stockholm is located. The exception is if the heating system consists of electrical resistance heaters, then the energy should be a maximum of 75 kWh/m^2.
2. The mean U-value of the construction parts (including thermal bridges) must not exceed 0.50 W/m^2K.

The ventilation norm requires 0.35l/s m^2 of fresh air. In the previous Swedish building code there was also a maximum value for the leakage through the building envelope on 0.8 l/s m^2.

The calculations performed with the recommended U-values (WEO reference and peak price scenario) match with these two requirements, when the air exchange rate from ventilation complies with the Swedish norm and no electricity heating is used (maximum demand: 110 kWh/m^2 per year).

The Netherlands

The recommended U-values for wall, floor, and roof from the analyses were taken as the input in the energy performance calculation carried out in accordance with the EPBD for a Dutch "reference dwelling" (in the NL the "epc calculation" according the NEN NPR 5129 as assigned in the national building decree "Bouwbesluit"). The performance requirement defined in the Dutch Building Decree is epc =< 0,8. With the calculated U-values this requirement has been met (WEO reference scenario: epc = 0,79; peak price scenario: epc = 0,77) without any special or additional installations and using the generic data for all other impacts on the performance the requirements also meet the "safety net" requirements on the component level U< 0,37 W/m^2K (Rc ≥ 2,5 m^2K/W).

Poland

The calculations performed with the recommended U-values (WEO reference and peak price scenario) for Poland result in buildings with energy performance "class E" and are meeting the requirements given for new buildings.

Spain

Calculations made by CENER from Spain conclude that for the two types of buildings located in Madrid, the U-values of the peak price scenario satisfy all energy requirements defined in section CTE DB HE-1 restriction of energy demand.

The two buildings located in Seville also meet the global energy demand even though the input U-value for the component floor is not in accordance with the local requirement in the climatic zone B (because of the negative effect of floor insulation on cooling demand which has been taken into account in the present study).

Even without external shading assumed in the calculations from CENER (an unfavourable situation which reduces the positive effect of insulation on cooling demand, as described in chapter 4.3) the calculations for both cities also show a reduced energy demand for cooling when implementing the U-values of the peak price scenario.

From the above verifications of the calculated U-values for Sweden, the Netherlands, Poland and Spain it is reasonable to conclude that the recommended U-values are in line with the corresponding national performance levels by referring to and being in accordance with the EPBD.

9] CONCLUSIONS

U-value optimum and cost effectiveness

Whether it is cost effective or not to start applying additional insulation, depends on the fixed costs per m², the starting point regarding U-value and the costs of saved energy. The study demonstrates that once the cost savings for heating and cooling energy exceed the total investment costs for insulation measures, the optimum U-value (mainly determined by the contribution of insulation) is, in any given location, identical for different insulation applications as long as no technical limitations occur. U-value optimum only depends on investment costs for the incremental centimetres of insulation and on the corresponding additional energy-cost-savings.

Recommendations for retrofit and for new buildings

As the U-value recommendations are robust against different initial levels of U-value and the fixed costs for insulation measures per m², the recommended optimum U-values apply to new and existing buildings.

Cost-efficiency and Post-Kyoto approach

Besides the economical analysis, a climate protection approach was able to identify the contribution of the residential buildings to the achievement of a 2050 CO_2 emissions reduction target of 85%, hence the U-value requirements for the total building stock. When comparing the U-values resulting from the economical and the climate protection approach, it is very interesting to note that they are comparable for any given region. This means that there are at least two fundamental argumentations, economic and environmental, to move requirements towards the U-values recommended.

U-values recommended versus current national building codes

Recommended optimum U-values resulting from the analyses based on cost-efficiency and Post-Kyoto targets are in most cases more ambitious than current national standards. The gaps differ significantly depending on countries and the building component envisaged. However, the current situation of energy prices justifies reviewing the U-value requirements in Europe.

Insulation and cooling energy demand

In residential buildings of southern Europe, thermal insulation also reduces the energy demand for cooling. Especially roof and wall, insulation provides very robust and considerable savings. A well balanced package of floor, wall and roof-insulation, combined with proper shading and a good ventilation strategy, results in a significant and cost-effective reduction in the energy demand for heating and cooling. This effect can be generalized for all residential buildings with reasonable passive cooling strategies and is quite robust in relation to “non designed behaviour” of tenants, or in case of a lower mass building.

10] REFERENCES AND EXTERNAL CONTRIBUTORS

Den Elzen, M.G.J. and M. Meinshausen. (2005). *Meeting the EU 2°C climate target: global and regional emission implications.* MNP-report, No. 728001031. Bilthoven, the Netherlands: Netherlands Environmental Assessment Agency (MNP). http://www.gci.org.uk/briefings/rivm.pdf.

Ecofys VI (June 2006) Sensitivity Analysis of Cost Effective Climate Protection in the EU Building Stock (Ecofys VI). Report for EURIMA European Insulation Manufacturers Association. Carsten Petersdorff, Thomas Boermans, June 2006

Ecofys IV/V (Aug. 2005) Cost-Effective Climate Protection in the Building Stock of the New EU Member States - Beyond the EU Directive on the Energy Performance of Buildings (Ecofys IV and V). Report for EURIMA European Insulation Manufacturers Association. August 2005

Ecofys III (Feb. 2005) Cost-Effective Climate Protection in the EU Building Stock (Ecofys III). Report for EURIMA European Insulation Manufacturers Association. Carsten Petersdorff, Thomas Boermans et al. February 2005

Ecofys II (Feb. 2004) Mitigation of CO2-emissions from the building stock – beyond the EU directive on the energy performance of buildings (Ecofys II). Report for EURIMA and EuroACE. Carsten Petersdorff, Thomas Boermans et al. February 2004

EU Council. (1996). Communication on Community Strategy on Climate Change, Council Conclusions. European Council, Brussels.

Eurima 2007: Overview of existing required or recommended U-values for 100 European cities. (April 2007)

EUROSTAT (2006) EUROSTAT database on http://epp.eurostat.ec.europa.eu

Höhne, N., D. Phylipsen, S. Ullrich and K. Blok. (2005). *Options for the second commitment period of the Kyoto Protocol, research report for the German Federal Environmental Agency.* Climate Change 02/05, ISSN 1611-8855. Berlin: ECOFYS GmbH. www.umweltbundesamt.de.

International Energy Agency (IEA): World energy outlook (WEO) 2006

IPCC. (2001). *Climate Change 2001: Mitigation.* Cambridge, UK: Cambridge University Press.

METEONORM. Meteonorm climate database V 5.1

PNNL: Pacific Northwest National Laboratory (PNNL); http://www.pnl.gov/

PRIMES Scenarios. Energy-Economy-Environment Modelling Laboratory ICCS/NTUA. http://www.e3mlab.ntua.gr/manuals/PRIMESld.pdf

TRNSYS. Thermal energy simulation tool. www.trnsys.com

UNFCCC. (1992). United Nations Framework Convention on Climate Change. Bonn: United Nations Framework Convention on Climate Change Secretariat. http://unfccc.int/resource/docs/convkp/conveng.pdf.

UNFCCC. (2006a). Issues relating to reducing emissions from deforestation in developing countries and recommendations on any further process. Submissions from Parties, FCCC/SBSTA/2006/MISC.5 (http://www.unfccc.int).

UNFCCC. (2006b). Views regarding Article 3, paragraph 9, of the Kyoto Protocol, Submissions from Parties, FCCC/KP/AWG/2006/MISC.1 (http://www.unfccc.int).

Build Desk The Netherlands

CENER Centro National de Energias Renovables, Spain

Mid Sweden University Anna Joelsson, Department of Engineering, Physics and Mathematics, Sweden

SEGEFA ULg Julien Charlier, Université de Liège, Belgium

University of Warsaw Prof. Alexander Panek, Poland

Contacts in national Energy Agencies, Universities, and Ministries who contributed with information on existing required U-values (see Annex 3)

Eurima *Market Development Committee* members and local representatives of member companies