733:U-values for better energy performance of residential buildings

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Beyond the overall Energy Performance requirement:
U-values for better energy performance of residential buildings

Optimum U-values calculated on the basis of cost-efficiency and CO_2-reduction targets are in most cases more ambitious than current national standards. This offers room for improvement in requirements within the EPBD-set, overall building performance and on building components. Designing on the basis of performance requirements that were defined when energy prices were less than a quarter of today's price, means that we are wasting money now and will continue to do so until the next building renovation. The minimum requirements for thermal performance of a building should reflect the average energy price for the estimated lifetime of the building.

For 100 European cities Eurima, the European Insulation Manufacturers Association, has quantified the gap between the required or recommended U-value and the economically optimum U-value. This gap in U-values means loss of money for society, for the building owner and the building occupant.

The Eurima study: "U-values for better energy performance of buildings" leads to the following conclusions:

- Once the cost savings for heating and cooling energy exceed the total investment costs for insulation measures, the optimum U-value (insulation thickness) 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.
- 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 and may well be 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.
- In residential buildings of southern Europe thermal insulation also reduces the energy demand for cooling. This is especially true for roof and wall insulation which combined with proper shading and a good ventilation strategy provides very robust and considerable savings. It is also true that a well-balanced package of floor, wall and roof-insulation measures results in a significant and cost effective reduction in the energy demand for heating and cooling.

Keywords:
energy regulations, component requirements, U-values, cost efficiency, optimum values

1. Time to adjust thermal requirements to the actual energy price.

Optimum U-values calculated on the basis of cost-efficiency and CO_2-reduction targets are in most cases more ambitious than current national standards. This offers room for improvement in requirements within the EPBD-set overall building performance and on building components.

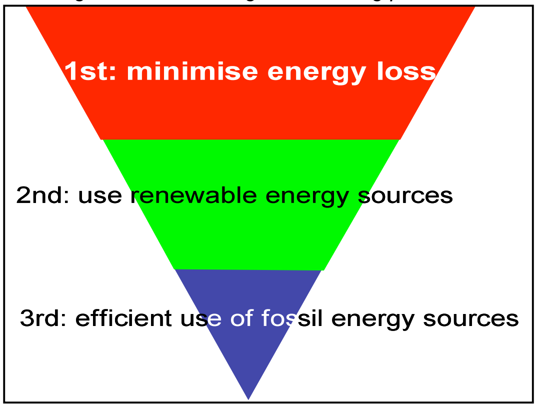
The Lisbon treaty encourages the EU-member states to revise their energy policies in order to make Europe more independent from foreign energy imports, create more jobs, make our economy more competitive and to improve our environmental profile.

Our thermal regulations are no longer sufficient in contributing to the Lisbon targets. The price of energy has never been as high as it is today with a price above 80 US dollar for a barrel of oil. Designing on the basis of performance requirements that were defined when energy prices were less than a quarter of today's price, means we are wasting money now and will continue to do so until the next building renovation. The minimum requirements in thermal performances of a building should reflect the average energy price for the estimated life time of the building. Doing less than the optimum corresponding to this oil price is wasting money for the building's occupant and brings economy and environment further away from the Lisbon goals! And as buildings are consuming 40% of Europe's energy there is an urgent need to revise our basic requirements for the thermal performances!

2. Calculated optimum for 100 cities

In many countries next to the EPBD required

Figure 1: Trias Energetica - setting priorities



overall building performance are additional requirements expressed in U-values or R-values on the maximum energy transmission for single building components. They reflect the knowledge that it saves money and improves comfort to first ensure a low energy demand of a building before supplying the remaining energy demand in the most efficient way. Giving priority to the minimization of energy losses through the building envelope follows the principles of the "Trias Energetica". (See **Error! Reference source not found.**) Many studies [1,2] have confirmed that good thermal insulation and air tightness of the building envelope are by far the most cost efficient measures to minimise energy use and to reduce building-use related emissions. However these national U-value requirements for building components, like roof, floor, wall, windows or doors, often describe minimum requirements that no longer reflect the economic optimum or specific environmental targets.

For 100 European cities Eurima [3] has quantified the gap in between the required or recommended U-value and the economically optimum U-value. This gap between the U-values means loss of money for society, for the building owner and building occupant.

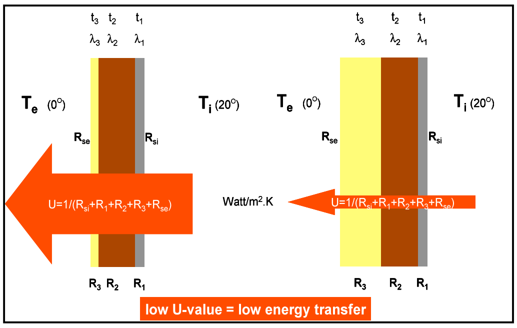
3. The role of U-values in practice

Requirements for the thermal transmittance of building components are playing a major role in the daily practice of the designing process and calculations for buildings. In the decisions to select measures for the renovation or thermal upgrading of a building the U-values is growing in importance.

Architects and specifiers use the U-value of building components as an initial, quick and easy design parameter. The main dimensions of the components in the building envelope are defined in the conceptual stage and will not be that easy to modify later. Apparently there are not that many consulting engineers that have the power and courage to advise the architect redesigning the concept that the energy efficiency measures are not optimal or even that they do not fit at all into the design. Even if they are not cost efficient modular "inserted" solutions must provide compliance with the overall EPBD performance requirements.

Unfortunately most architects and designers do not apply an integrated energy calculation of the overall building according the EPBD, but prefer working in this modular approach. Architects and designers are usually very strong in integrating approaches however it seems that energy efficiency measures are not yet part of that integrated thinking. For them energy efficiency measures are of concern in a later stage in the

Figure 2 : U-value: low U-value means low energy transfer



planning process. In most EU countries architects hand over their design to other specialists that then have to sort out and find a solution of how to comply with the legal or the customer's energy requirements. The nice design and appearance of the building envelope prevails above a well balanced decision on how energy efficiency measures and supply measures are integrated in the building conceptual design. There is no "room" left in the building's envelope for increasing insulation thickness, better glazing, shading, etc. The first priority of the Trias Energetica cannot be respected and less cost effective solutions are found as a second or even third priority.

U-values have a key role in the implementation of the design process: U-values are the architect's first (and perhaps only) guidance for fixing the dimensions for the components wall, roof and floor in the building's envelope. The construction products supply industry answers the requests from architects and designers by providing technical documentation that specifies these U-values for the building components.

4. All EU countries use U-values

The EPBD (Energy Performance of Buildings Directive) calculations in all EU member states take precedence to the component requirements calculations for setting the overall energy performance of the building. The calculations of this overall energy performance of buildings 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 for the fully integrated overall energy performance.

Next to this overall building energy performance requirement, component requirements exist in almost every EU country but are a second level requirement. U-value requirements originate from times when only component requirements were used to achieve energy savings, and were used to provide safety margins for avoiding surface condensation and to avoid low surface temperatures that cause thermal discomfort. In the study an overview is given of the existing U-values that are required or recommended in the 100 European cities that were analysed. The cities represent different climate conditions in all member states of the European Commission as well in Norway, Switzerland and the Balkan countries.

5. Aim of the study

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 basis of an economic optimum.

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 study does not optimise between the possible energy demand reduction 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 combinations of insulation measures were defined to assess the influence of insulation on cooling. In addition, the 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.

The results for the optimum U-values are based on:

- the climate data in 100 European cities
- the economic optimum U-value (heat transmission value in W/m2K) 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.

6. Reference Buildings and climate conditions

Building types in the residential sector and their construction types vary from region to region, from country to country. For this approach two reference buildings were taken and the following specifications for the construction types were defined:

- 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

For both reference buildings representative characteristics like the thermal inertia, internal heat gain, shading of windows and day and night ventilation, were defined.

For the analysis of the energy demand for cooling a sensitivity analysis also studied the effect of a building with a low thermal mass. In the sensitivity analysis for the U-values on the cooling demand the effect of shading, internal heat production and night ventilation were taken as impact parameters

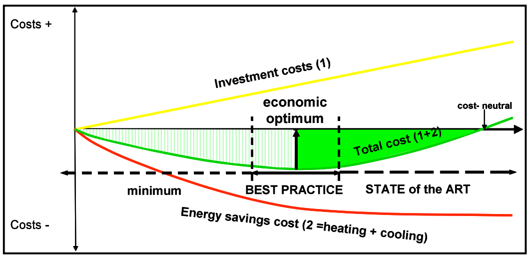


Figure 3: Economic optimum

The calculations on the optimum U-values have been performed with the thermal simulation programme TRNSYS. The climate data taken into account for the 100 selected cities are based on climate data from METEONORM.

7. Economic optimum

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.

For each of the 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 **Error! Reference source not found.**

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. 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 **Error! Reference source not found.**) 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.

The curve for the cost savings shows a typical development against increasing insulation thickness with especially large savings generated by the first few centimeters of insulation. Building types in the residential sector and their construction types vary from region to region, from country to country. For this approach two reference buildings were taken and the following specifications for the construction types were defined:

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8. Results applicable for new buildings and for renovation

The optimal U-value from an economic point of view 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 at all (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.

9. Environmental optimum

The objective is to stabilise greenhouse gas concentrations to avoid dangerous anthropogenic interference with the climate system. This target 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.

It is likely that emissions in the building sector in the EU will have to be reduced more than the average over all sectors. 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% CO_2-emission-savings until 2050 based on 1990 levels.

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. The European building stock in 1990 was dominated (and still is) by single family houses built before 1975 that have not yet been renovated. This type of buildings has therefore been chosen as the reference situation [4]. Houses built before 1975 have not usually 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. And in order 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.

10. Price scenarios and investment costs

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 Eurima-Ecofys-studies, expressed as average values in zoned levels for:

- cold zone of EU15 (+ Norway)
- moderate zone of EU15 (+ Switzerland)
- warm zone of EU15 (+ Portugal)
- New EU-8 (+ Romania, Bulgaria, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, Macedonia and Albania)

The study gives optimum U-value recommendations for two price scenarios.

- Scenario "WEO 2006 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 2006. The average increase in costs is assumed to be 1,5% per annum

- 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.

In the energy mix for the before mentioned zones the dependency of the price for gas and district heating on the oil price has been taken into account. Also prices for other energy carriers have been adapted accordingly. For cooling appliances the use of electric systems has been assumed to be applicable in most cases.

The before mentioned assumptions on price scenarios and fuel mixes lead to the following average prices as given in **Error! Reference source not found.** below.

Table 1: resulting average energy prices 2006-2036 in cents/kWh end energy including tax

Cent/kWh	WEO reference	Peak price
EU15 northern	9.62	12.03
EU15 moderate	7.80	10.61
EU15 south	7.71	10.59
New 8	6.40	8.33

11. Comparison of results: cost efficient U-values versus required U-values

- Cost-efficiency vs. Post Kyoto:
  In general, the recommendations based on cost-efficiency are similar to the recommendations derived from possible Post Kyoto targets.
  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.
- Insulation and cooling:
  A sound package of insulation measures has a positive effect on cooling demand of residential buildings. 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. With the issue of cooling energy included, this leads to a reduction of the cooling demand through lower U-values for roofs and a negative impact on the cooling demand with lower U-values for floors in southern Europe.
- Recommendations for retrofit and for new buildings:
  With usually the same costs per centimeter of insulation added in retrofit actions and in new building activities, the optimum U-value, if insulation is applied, is the same in retrofit actions and in the situation of new buildings and is valid for different insulation applications, which mainly affect the fixed costs per m².
- Cost efficiency and current national building codes:
  Recommended maximum U-values resulting from the analyses based on cost-efficiency and Post Kyoto targets are in most cases more ambitious than current national standards.

In combining the results of the calculations with the required U-values the following figures can be drawn. The figures [4 and 5] may visualise the gap between the existing minimum requirements and what on the basis of today’s (Mai-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 the report on this as available on the website of Eurima [5]

12 Conclusions

The Eurima study: “U-values for better energy performance of buildings” leads to the following conclusions:

- Once the cost savings for heating and cooling energy exceed the total investment costs for insulation measures, the optimum U-value (insulation thickness) 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.
- 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.
- 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.

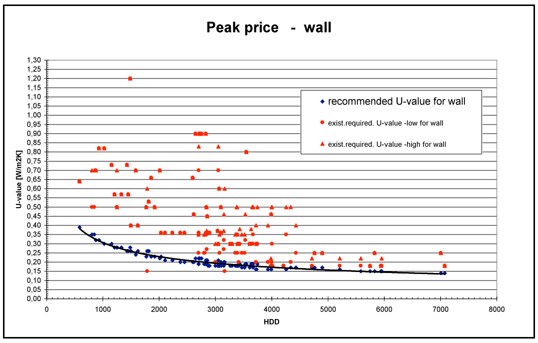

Figure 4: required and optimum U-values for wall constructions relate to energy demand for heating

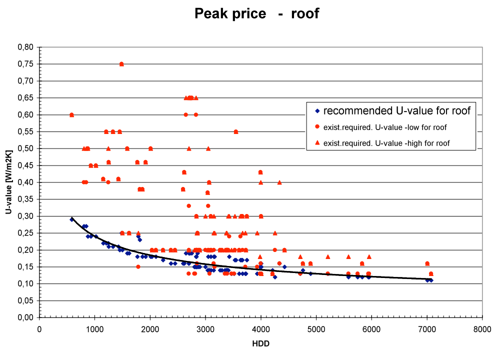

Figure 5: required and optimum U-values for roof constructions related to energy demand for heating

13. References

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-Cost-Effective Climate Protection in the EU Building Stock:
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http://www.eurima.org/downloads/ecofys_repoft_final_160204.pdf
-Cost-Effective Climate Protection in the Building Stock of the New EU Member States:
http://www.eurima.org/downloads/ECOFYS4_V07.pdf

2 Vattenfall-McKinsey reports: Global Mapping of Greenhouse Gas Abatement Opportunities up to 2030*:*
http://www.vattenfall.com/www/ccc/ccc/577730downl/index.jsp

3 Eurima: European Insulation Manufacturers Association, Brussels. www.eurima.org

4 The specification of the reference single family house and the qualities assumed for the building envelope has been taken from the Eurima-Ecofys reports II to V. see
http://www.eurima.org/document_library/eurima_publications.cfm#top

5 Report on the study U-values for better energy performance of buildings see:
http://www.eurima.org/document_library/eurima_publications.cfm#top