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1 Introduction

This report summarises the work performed within the Concerted Action Energy Performance of Buildings Directive (CA EPBD) from January 2011 to May 2014 in order to meet the European Commission's requirement for calculating cost-optimal levels of buildings' energy performance for new and existing buildings. The requirement for performing the calculations is stated in the Energy Performance of Buildings Directive (EPBD - Directive 2010/31/EU[1]). The calculation procedure is outlined in the comparative methodology framework[2] for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

The CA EPBD is an activity that aims to foster exchange of information and lessons learned among all Member States (MSs) and Norway with regard to the implementation of the specific Community legislation and policy on the energy performance of buildings. It involves the national authorities implementing the EPBD, or those bodies appointed and entrusted by them to do so. The CA EPBD consortium is composed of organisations designated by all 28 MSs plus Norway. The CA EPBD is financed by the EU's Intelligent Energy Europe Programme[3].

The EPBD (Directive 2010/31/EU) requires MSs to: "*ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels*". MSs should also: "*take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels*" (EPBD Art. 4.1 and also in recital 14).

[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF
[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32012R0244:EN:NOT
[3] http://ec.europa.eu/energy/intelligent/index_en.html

The cost-optimal level is defined as "*the energy performance level which leads to the lowest cost during the estimated economic lifecycle*". MSs will determine this level taking into account a range of costs, namely, investments, maintenance, operating costs and energy savings. The economic life cycle is defined individually by each MS. It refers to the estimated economic life cycle of a building or building element. Cost-optimal solutions by definition are also cost-effective (EPBD Art. 2.14).

The EPBD requires MSs to report on the comparison between the minimum energy performance requirements and the calculated cost-optimal levels using the comparative methodology framework provided by the Commission (EPBD Art. 5.2, 5.3 and 5.4, and Annex III) and accompanying Guidelines. The report shall also provide all input data and assumptions made. The comparative methodology framework is accompanied by guidelines from the Commission to enable the MSs to:

- Define at least 9 reference buildings that are characterised by and representative of their functionality and climate conditions. The reference buildings must cover residential and non-residential buildings, both new and existing ones.
- Define energy efficiency measures, the effect of which is to be assessed for the reference buildings. These may be measures for buildings as a whole, for building elements, or for a combination of building elements.
- Assess the final and primary energy demand of the reference buildings, as well as the reference buildings with their defined energy efficiency measures applied.
- Calculate the costs (i.e., the net present value) of the energy efficiency measures during the expected economic life cycle applied to the reference buildings, taking into account investment costs, maintenance and operating costs, as well as earnings from energy produced.

The CA EPBD report "Cost-optimal levels for energy performance requirements"[4] provides more details about the calculation methodology.

MSs must report to the Commission all input data and assumptions used for these calculations, as well as the results of the calculations, from two perspectives: the societal perspective, and the perspective of the private investor. MSs can then choose which one to apply at the national or regional level.

The Commission provides the needed information on the estimated long-term energy price developments.

The EPBD does not demand that MSs set their minimum energy performance requirements at levels that are cost-optimal. It does however require them to report how their requirements differ from cost-optimal levels (implicitly as far as underperformance is concerned). If there are "significant" differences – exceeding 15% (meaning that they allow energy consumptions that are 15% higher than what cost-optimal levels would be) - MSs should justify them, or plan steps to reduce the difference. Clearly, this first requires the calculation of a cost-optimal requirement. The report "Assessment of cost-optimal calculations in the context of the EPBD (ENER/C3/2013-414)"[5], requested by the Commission and published in November 2015, summarises the MSs progress in this matter.

Information collected in the present report aims to merge relevant knowhow and experience concerning carrying out calculations of cost-optimal energy performance levels, comparison of the calculated levels with the national requirements, and implications on the national requirements for the energy performance of new and existing buildings. Additionally, lessons learned from MSs' cost-optimal calculation exercises have been shared with CA EPBD members and will form a valuable basis for the next round of calculations, which are expected to be carried out within 5 years from the first.

All national reports on the calculation of cost-optimal levels of minimum energy performance requirements are available on the EC website[6]. This report covers both early and recent lesson learned by MSs and information is primarily based on MSs' presentations given at the CA EPBD meetings, i.e., from 16 countries.

2 Calculating the cost-optimal levels

The methodology for calculating the cost-optimal energy performance levels seems to work in practice and delivers interesting results, while the effort needed to do the calculations is manageable. Calculation of numerous variants of energy-saving measures, or packages of measures, is necessary in order to obtain more accurate cost-optimal values. A minimum of 10 variants per reference building must be calculated in order to identify the cost-optimal level, but 20-40 variants would be the ideal number in order to identify the cost-optimal level clearly.

[4] http://www.epbd-ca.org/Medias/Pdf/Cost_optimal_levels_for_energy_performance_requirements.pdf

[5] https://ec.europa.eu/energy/sites/ener/files/documents/Assessment%20of%20cost%20optimal%20calculations%20in%20the%20context%20of%20the%20EPBD_Final.pdf

[6] ec.europa.eu/energy/efficiency/buildings/implementation_en.htm

Use of only 1 reference building per building type does not cover the real lack of homogeneity of the building stock. According to the experiences from test runs, 3-4 reference buildings for each building type would be needed in order to get a clear picture of the building stock diversity. Many of the calculated cost curves are quite flat and no single clear optimal point could be identified, but rather a cost-optimal range.

When analysing the existing building stock, it is possible to identify a large number of different building types due to differences in construction and use. Based on this, some MSs (e.g., The Netherlands) have defined up to 184 different reference buildings to be able to describe their building stock, while many others simply use the minimum number prescribed in the Guidelines accompanying the comparative methodology framework.

For any reference building, a number of variations on packages of energy saving measures must be calculated in order to identify the cost-optimal level. There is a large diversity in the number of calculations carried out in different MSs. The Flemish Region of Belgium, for example, used stochastic variations of the measures and calculated more than 100,000 variants for each reference building. Other MSs have carefully selected the measures among logical packages and have limited the number of calculations significantly.

MSs have carried out calculations of their cost-optimal levels since 2011, and some even before the development of the Guidelines, published in April 2012. Lessons learned do vary significantly among MSs, but all recorded lessons learned from CA EPBD have been of great value for the development of both the current Guidelines and the future revised version for the next round of calculations to take place 5 years after this first round.

Many MSs have experienced that the cost-optimal levels are not easily identified and it is a band of more or less equally cost-optimal solutions that define the cost-optimal level, rather than one single solution combining the building envelope and the technical systems. The curves that can be drawn between the calculated combinations show a flat curve around the optimal level. Figure 1 shows results from a test run of the cost-optimal calculations of a new office building located in Austria.

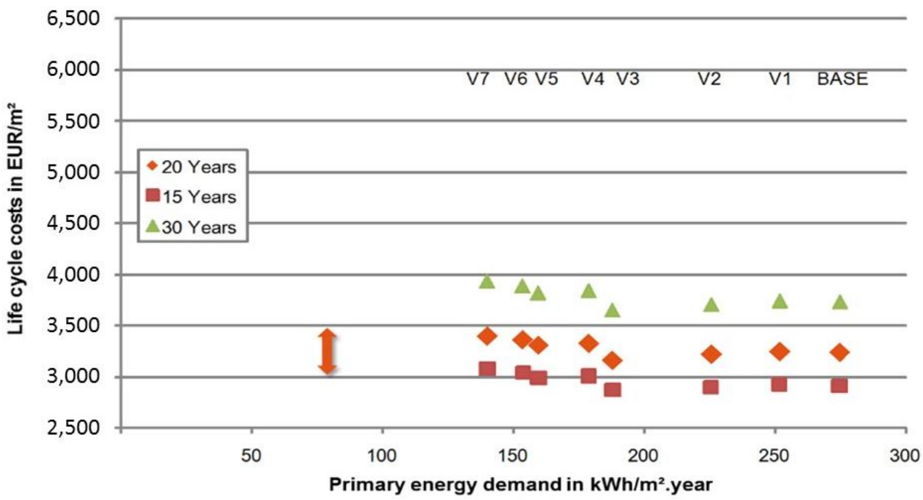

Figure 1. Results from the calculation of the life-cycle cost for different combinations of energy-saving measures using 3 different life times for the measures on a new office building. The cost-optimal level is not one point, but can be identified as a collection of equally good results, ranging from 225 to 180 kWh/m².year, depending on the energy-saving package variation.

The outdoor climate significantly influences the energy needs in buildings and in some MSs there are broad variations in the climate. Most of these MSs have thus divided the country into climatic regions with different energy performance requirements and different calculated cost-optimal levels. In other MSs, however, it has been decided that it should not be more expensive to construct a building in one region compared to another, and they use only one set of climate data for setting requirements and calculating the cost-optimal levels in the whole country.

MSs include Renewable Energy Sources (RES) in the calculation of the cost-optimal levels according to their national legislation. RES production can be divided into 3 categories, namely production of electricity, production of heat and production of cooling.

Production of electricity can come from various RES and MSs have indicated acceptance of electricity production from solar cells (PV), local wind turbines, combined heat and power (CHP) production, and electricity produced by hydro plants (Figure 2).

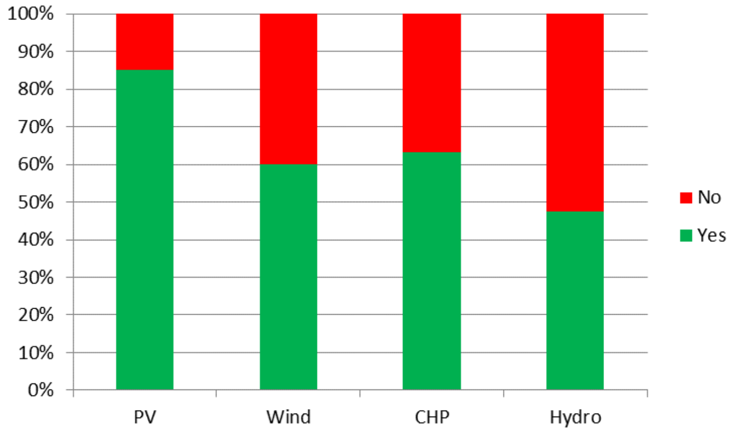

Figure 2. Electricity produced from various RES is included in the building energy performance. Most MSs allow inclusion of electricity from PV, while fewer also allow electricity from wind and CPH. Only approximately half of the MSs state that electricity from hydro power can be included in energy performance of buildings.

Production of heat from RES is, like production of electricity, accounted for differently in different MSs. Here, the diversity in possible sources for heat production is much larger than for production of electricity and handling these different sources varies significantly (Figure 3).

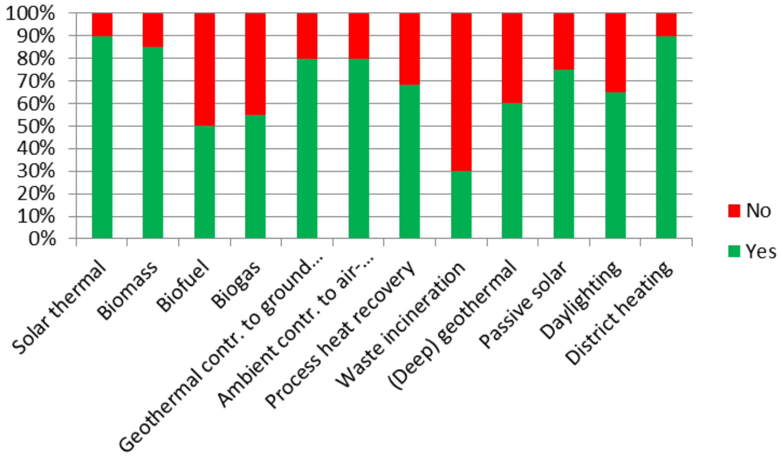

Figure 3. Heat sources by RES included in MSs national legislation.

Production of cooling from RES is an option primarily in the Southern parts of Europe and, except passive cooling, less than half of the MSs include cooling generation from RES in their legislation (Figure 4).

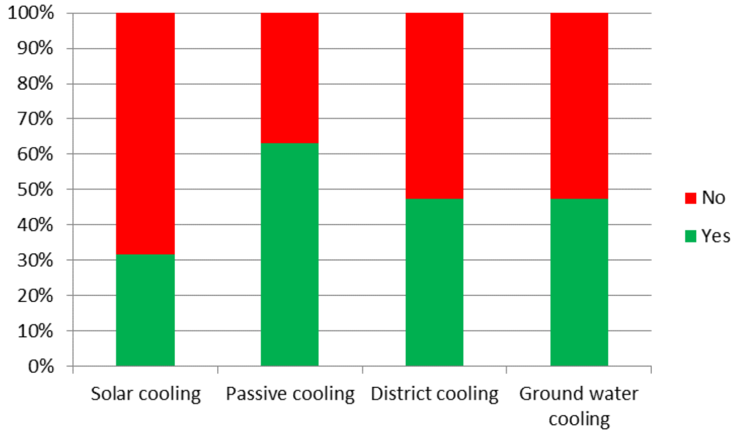

Figure 4. Cooling generation from RES sources included in MSs legislation regarding the energy performance of buildings. A large number of the MSs do not take into account cooling from RES sources in the energy performance of buildings.

3 Implications on current requirements from calculating the cost-optimal levels in EU Member States

Examples from selected MSs calculations of the cost-optimal levels for new and existing buildings are given below to illustrate the huge variety among MSs in their challenge to set requirements that are within the acceptable range of 15% from the calculated cost-optimal level.

In the **Flemish Region of Belgium**, the cost-optimal level for residential and non-residential buildings was calculated in the spring of 2013. In Belgium, the primary energy use (kWh/m².year) is not an indicator for checking compliance with the building regulations. The so-called E-level (primary energy consumption divided by a reference value) is used instead. The results for the Flemish Region indicate that the cost-optimal for residential buildings with PV is E50, which should be compared with the 2014 requirement of E60. For offices and schools, the cost-optimal level without PV is E60, which is the same as defined in the Flemish Building Regulations 2014.

In the expected 2021 Flemish Building Regulations, E-level requirements are E30 for residential buildings and E40 for offices and schools. These requirement levels are cost-effective.

Table 1 summarises the cost-optimal levels in comparison with the energy requirements for new buildings in the **Danish** Building Regulations 2010 (BR10). Analyses are based on the financial (private) perspective. The gap is shown in % of the cost-optimal level of requirements in kWh/m².year primary energy, inclusive RES. A negative gap indicates that the requirements in the Danish BR10 are tighter than the cost-optimal level. BR10 is the present minimum requirement allowed by the Danish Building Regulations. LEB2015 is the voluntary Low Energy class 2015 - already defined in the BR10 requirements for 2015. B2020 is the voluntary Building class 2020 - already defined in the BR10 requirements for 2020. Only the relevant heat supply sources in relation to Danish heat plans are included in the calculations.

Table 1. Cost-optimal of the energy requirements for new buildings in the Danish Building Regulations 2010. For the different building types and heat supply the table shows the cost-optimal in kWh/m².year primary energy and the gap between the cost-optimal level and the Danish requirements in %.

Building type	Heat supply	Cost-optimal kWh/m².year	Deviation from cost optimal in %		
			BR10	LEB2015	B2020
Single-family house	District heating	68.7	-15.7%	-44.9%	-57.0%
	Heat pump	51.1	-2.8%	-49.8%	-58.0%
Multi-family house	District heating	53.6	-9.2%	-36.1%	-44.7%
Office building	District heating	51.7	31.2%	-16.0%	-37.3%
Weighted average	DK mix		2.8%	-34.4%	-48.8%

In relation to the new housing examples, the present minimum energy requirements in BR10 all show gaps that are negative, with a deviation of up to 16% from the cost-optimal point. With the tightening of the requirements for new houses in 2015 and the planned tightening in 2020, the energy requirements can be expected to be tighter than the cost-optimal point, if the costs for the needed improvements do not decrease correspondingly.

In relation to new office buildings, there is a gap of 31% to the point of cost-optimality in relation to the 2010 requirement. In relation to the 2015 and 2020 requirements there are negative gaps to the point of cost-optimality based on today's prices.

If the gaps for all new buildings are weighted to an average based on a mix of building types and heat supply for new buildings in Denmark, there is a gap of 3% on average for new buildings. The excessive tightness with today's prices is 34% in relation to the 2015 requirement and 49% in relation to the 2020 requirement.

The calculated cost-optimal curves in **Germany** were very flat, as in other cases with high insulation standards as the starting point, and the cost-optimal level was an interval rather than a single point. In the example shown in Figure 5, the optimal insulation thickness is 11 cm, but applying an uncertainty of ± 2% on the optimal point leads to an optimal interval of insulation thickness ranging from 5 to 20 cm. Any thickness between 5 and 20 cm is thus a valid value as the optimal thickness in this case.

A sensitivity analysis was carried out and the results plotted in a radar diagram in order to investigate which parameter influenced the life-cycle cost the most. Considering the averages, (Figure 6) most parameters have equal impact on the life-cycle cost, but some parameters, e.g., the energy price and the general price development, result in the most significant variations in the cost calculation results.

Analysing different combinations of thermal envelope quality and technical building installations, the optimal value for the primary energy consumption was 13 to 22% less than required in the 2011 German Building Energy Regulations for new buildings.

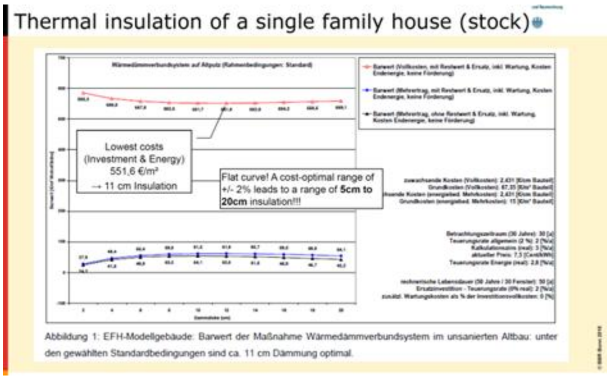

Figure 5. Calculated cost-optimal curve for a German single-family house.

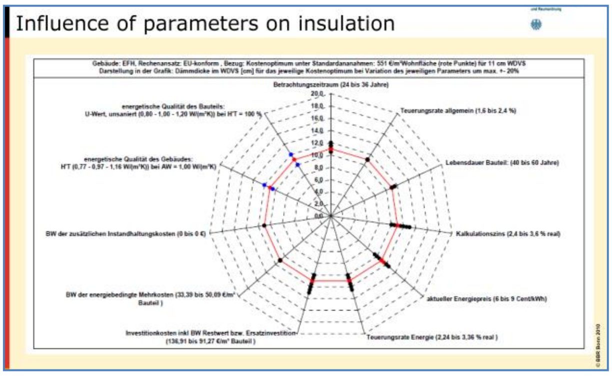

Figure 6. The influence from different parameters on the calculated cost-optimal level.

For new buildings, **Ireland** operates with whole building energy performance requirements, while component requirements are used for existing buildings. A comparison of the 2013 requirements and the calculated cost-optimal levels are shown in Table 2 and 3.

For all types of existing buildings, most of the Irish 2013 component requirements are significantly more lax than the calculated cost-optimal levels. The component level performance standards in this regulation were last reviewed in 2002. The Irish Regulation and Technical Guidance Document are currently undergoing a review process. It is intended that the new Regulation and Guidance for components will be reviewed in light of cost-optimal levels for components.

Table 2. Comparison of cost-optimal levels and current energy performance requirements for new Irish residential buildings.

Reference building	Cost optimal range (kWh/m².year)	Current requirements (kWh/m².year)	Current requirements and cost-optimal level
Bungalow	33-139	67	Current requirements are within the cost-optimal range
Detached house	45-113	55	
Semi-detached house	49-110	54	
Mid-floor flat	57-94	57	
Top-floor flat	68-105	65	
Average	**50-112**	**60**	

Table 3. Comparison of cost-optimal levels and current energy performance requirements for new Irish non-residential buildings.

Reference building	Cost-optimal range (kWh/m².year)	Current requirements (kWh/m².year)	Current requirements and cost-optimal level
Retail (air conditioned)	239	726	The current requirements are more than 15% above the cost-optimal level
Office (natural ventilation)	52	247	
Office (air conditioned)	102	366	
School (natural ventilation)	55	111	
Hotel (air conditioned)	284	507	
Average	**146**	**391**	

It is worth reviewing the uncertainty shown in the sensitivity results. When the maximum in the range for each reference building is taken, the current technical standards are 90% above the cost-optimal level. This provides confidence that the 2013 standards are more than 15% above cost-optimal levels, which the cost-optimal Regulations define as a significant difference.

The assessment in **Lithuania**, based on 2012 energy and fuel prices, showed that the 2014 U-value requirements for walls, roofs and floors over unheated basements and underground cellars in new buildings, are 33% to 114% too high compared with the cost-optimal level (C class). Likewise, the current U-value requirements for doors and windows in new buildings are between 81% and 106% too high compared with the cost-optimal level. For existing buildings, the current requirements are 65% to 200% too lax compared with the cost-optimal level (D class). U-value requirements for windows in existing buildings subject to major renovation are 75% to 97% too high compared with the cost-optimal level. For doors, the current U-value requirements are between 7% and 36% too high.

Calculations of the cost-optimal levels for new **Maltese** residential units (houses and apartments) showed that the cost-optimal levels for the various reference buildings are significantly lower than the 2014 minimum energy performance requirements (Table 4). Three prime possibilities for bridging the gap between the cost-optimal level and the current minimum requirements have been identified:

- adjustment of U-values for walls, windows, and floors;
- inclusion of a requirement or promotion for renewable energy for new residential units in the form of solar water heating or photovoltaics, wherever possible;
- promotion of alternatives to electric water heating, where solar water heating is not possible.

Table 4. Calculated cost-optimal levels (sensitivity range) for new residential units compared with the current minimum energy performance requirements.

Reference building type	Sensitivity range kWh/m².year	Current requirements kWh/m².year
Detached villa	5 to 75	94
Semi-detached villa	5 to 50	84
Terraced house	5 to 50	82
Top floor maisonette	0 to 70	97
Ground floor maisonette	-10 to 80	127
Top floor flat	-60 to 60	125
Mid-floor flat	-60 to 40	117

For non-residential buildings, 9 reference buildings (office buildings) have been identified and calculated to find the cost-optimal levels for energy performance. Each reference building has been subject to packages of energy-saving measures, including 4 variations of the thermal envelope, 4 system variations and 2 different options for inclusion of renewable energy systems. All analyses were based on building component analyses. For residential units, the cost-optimal levels are significantly more tight than the current requirements, for both new and existing buildings.

Calculations of energy performance of reference buildings in **Slovakia** (11 different reference buildings) were used to identify cost-optimal levels for individual building elements. Only the building element investigated was varied, keeping the rest of the building elements at the current minimum requirement level. Variations were made step-wise, with increments of 20 mm of insulation material for the opaque building elements. Variants of windows were selected among possible combinations of glass and frame types from real manufactures. Table 5 shows the cost-optimal element levels, the 2013 levels and the 2015 levels.

Table 5. Implications and deviations from the cost-optimal level in the current Slovak Building Regulations concerning the building element requirements for new and existing buildings (U-values; W/m².K).

Building construction	Cost-optimal level W/m².K	Current requirement level W/m².K	Requirement after 2015 W/m².K
External walls	0.21	0.32	0.22
Gap		-52%	-5%
Roofs	0.18	0.20	0.10
Gap		-11%	44%
Unheated space (Δt < 20 K)	0.37	0.75	0.50
Gap		-103%	-35%
Windows	0.90	1.4	1.0
g-value	0.62		
Gap		-56%	-11%

Based on the calculated cost-optimal levels for the individual building elements, packages of measures were applied to the reference buildings with the 3 first element levels lower than the optimal point. The packages consisted of variations on energy supply systems. In total, 584 packages were calculated (45-55 packages per residential building and 70-90 packages per non-residential building), e.g., for a block of flats, 55 variants were calculated as combinations of heating systems, systems for domestic hot water and the building envelope. The level of energy performance was derived from these calculations as current minimum requirement 126 kWh/m².year, the recommended (2015) value is 63 kWh/m².year and the target for 2020 (i.e., Nearly Zero-Energy Buildings - NZEB) is 32 kWh/m².year.

From calculations of the cost-optimal energy performance levels, it became clear that the requirements in Slovakia after 2015 will all become stricter (12-27%) compared with the 2013 requirements. The minimum requirements valid after 2015 are already cost-optimal or stricter, therefore only minor changes in legislation were needed. One of the lessons learned from the calculations is that more strict requirements from 2013 and 2015 are reasonable and needed. Furthermore, the calculations showed that there is no significant difference in the cost-optimal level between new and existing buildings. The calculation exercise was based on theory and assumptions regarding the buildings and the technical possibilities, and technical feasibility may prove to be the main problem for implementation of energy-saving measures in existing buildings. In future, adaptation of requirement to the availability of RES/heat generation will need to be implemented. This will require that minimum requirements for primary energy should reflect the availability of RES to avoid the loss of the potential for energy savings by improving the building envelope. It should thus only be the generally feasible solutions that are considered for minimum requirements, while higher energy performance could be cost-optimal only in localities where sufficient RES are available.

As a result of the **Spanish** cost-optimal analyses, it was suggested that the energy requirements for new buildings in Spain must be tightened to about 80% of the cost-optimal level in the 2013 Building Regulations. This improvement can be reached by a “reduced” package of energy-saving measures in 80% of the tested buildings. The cost-optimal levels for the opaque parts of the thermal envelope in the five winter climatic zones are shown in Table 6, in combination with the current requirements and suggestions for new requirements. The suggested new regulation will result in an average energy saving in Spain of approximately 30% in all new buildings.

The results clearly show a need for drastic measures (at least in the Madrid region). MSs are requested to provide a roadmap for reaching the cost-optimal level over a specific period of time. In the Spanish case, a new revision of the Building Energy Regulations is foreseen for 2016 and it is anticipated that the cost-optimal level will then become the minimum requirement for all new buildings in Spain.

Table 6. Calculated cost-optimal levels for opaque constructions in the 5 Spanish climate zones (A-E), compared with the current (before 2012) requirements and the suggested new requirements.

U-values		**Climatic Zone**				
(W/m².K)	U (Walls)	A	B	C	D	E
	Single-family	0.28	0.23	0.18	0.17	0.14
	Block of flats	0.27	0.22	0.18	0.15	0.13
	Current code	0.94	0.94	0.82	0.82	0.73
	New 2011 code	0.50	0.38	0.29	0.27	0.25
(W/m².K)	U (Roofs)		B	C	D	E
	Single-family	0.22	0.19	0.17	0.15	0.12
	Block of flats	0.24	0.22	0.18	0.17	0.15
	Current code	0.50	0.50	0.45	0.45	0.41
	New 2011 code	0.47	0.33	0.23	0.22	0.19
(W/m².K)	U (Floors)		B	C	D	E
	Single-family	0.36	0.30	0.24	0.20	0.17
	Block of flats	0.34	0.30	0.25	0.22	0.20
	Current code	0.53	0.53	0.52	0.52	0.50
	New 2011 code	0.53	0.46	0.36	0.34	0.31

4 Conclusions

Many MSs have experienced that one or more building types have more lax energy performance requirements than the calculated cost-optimal levels. In many cases, the new, stricter energy performance requirements have already been included in the national legislations, or will soon become national minimum requirements.

In most MSs, especially in countries where the current energy performance requirements are strict, the curves showing the lifecycle costs for different performances is rather flat around the cost-optimal level. It is thus not possible to identify one single combination of measures to be the cost-optimal level, but it is rather a band of combinations that are equally cost-optimal. In most of these cases, MSs have chosen to set the minimum energy performance level in the lower end of the range of equally valid cost-optimal levels.

The calculation procedure carried out in MSs differs significantly in terms of number of reference buildings, climate data sets, packages of measures, and calculations carried out for each combination. Presentation of the calculation results from MSs reflects this large diversity.

The MSs’ reports on the calculation of cost-optimal energy performance levels have been validated by an external consultant selected by the EC. Some general findings can be drawn:

- Reference buildings have been defined in MSs in more or less the same manner.
- Some MSs did not calculate the cost-optimal level for new buildings.
- Only a few MSs delivered results on both building and component level for existing buildings.
- For calculating packages of energy renovation measures in existing buildings, one reference building is not enough.

The question of component requirements versus whole building requirements in case of major renovations was raised. In the early days of the CA EPBD discussions on cost-optimal calculations, it was suggested that the two methods could be considered equally valid. In the current assessment of the MSs’ reports, it seems that it is required to deliver results from both analyses in the reports. There is little doubt that the EPBD is unclear on this point, but the general interpretation seems to be that both sets of checks need to be done.

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