# The current proposal for an energy label for windows

## Brief Analysis of Pros and Cons

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**By: Dr. Andreas H. Hermelink, Dr. Nesen Sürmeli-Anac, Bernhard von Manteuffel, Ashok John, Sven Schimschar**

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Reviewer:
Sven Schimschar

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**ECOFYS Germany GmbH** | Albrechtstraße 10 c | 10117 Berlin | **T** +49 (0)30 29773579-0 | **F** +49 (0)30 29773579-99 | **E** info@ecofys.com | **I** www.ecofys.com

**Managing Director** C. Petersdorff | **Register Court:** Local Court Cologne | **Chamber of commerce Cologne** HRB 28527 | **VAT ID** DE 187378615

# 1 Introduction – Documents under review

On 22 June 2015 the consolidated 295 pages final report (Task 7) "Policy Options & Scenario analysis of the 'ENER Lot 32' Ecodesign Preparatory study, prepared by VHK and ift Rosenheim, in collaboration with VITO was published. The very comprehensive report concludes "that Energy Labelling offers the best approach to address the barriers and opportunities that have been identified, while respecting and adding to the existing legal framework." (van Elburg et al. 2015a, p. 3)

Based on that recommendation to take the energy labelling route for windows the European Commission (EC) amongst others has prepared two *working documents* which were sent out on 2 September 2015 together with the invitation to a stakeholder consultation forum in Brussels on 30 September 2015 where these working documents are to be discussed:

- regulation on energy labelling of windows that was corrected by the EC on 9 September 2015 (European Commission (EC) 2015b) and
- an explanatory memorandum to that regulation (European Commission (EC) 2015a) that was corrected by the EC on 9 September 2015, too.

Velux A/S has asked Ecofys to independently, but briefly evaluate these documents and the underlying Task 7 report ahead of the consultation forum on 30 September 2015. Main aspects to be addressed are the extent to which the current proposal meets the requirements usually attached to the implementation of an energy label, the energy balance calculations, and the proposal for ranking of windows that should avoid misguiding consumers.

Due to time restrictions the analysis strongly focuses on heating energy related to vertical windows in residential buildings.

# 2 Analysis and evaluation of requirements that lead the route towards energy labelling for windows

## 2.1 Criteria to be met for delegated acts according to Article 10 Energy Labelling directive

According to Article 10 of the Energy Labelling Directive (European Union (EU) 2010) the following criteria need to be met in order for a product type to be eligible for the development and application of an energy label:

*"(a) according to most recently available figures and considering the quantities placed on the Union market, the products shall have a* ***significant potential for saving energy*** *and, where relevant, other essential resources;*
*(b) products with equivalent functionality available on the market shall have a* ***wide disparity in the relevant performance levels****;*
*(c) the Commission shall take into account* ***relevant Union legislation and self-regulation****, such as voluntary agreements, which are expected to achieve the policy objectives more quickly or at lesser expense than mandatory requirements."*

### 2.1.1 Criterion a) Significant potential for saving energy

**Plausibility check of BAU scenario**

As the BAU scenario is the crucial reference for evaluating potential additional savings of a window energy label we performed a quick plausibility check for the numbers given in BAU. Note that BAU is the baseline scenario, i.e. it assumes a future development that would occur *without the implementation of an energy label for windows*.

In the following we describe our steps for cross-checking the plausibility.

**Window area**

First we tried to reproduce the total window area, which in BAU is assumed to be 4.1 billion m$^2$ for residential buildings. For this purpose we combined the following information also given in Task 7 report (van Elburg et al. 2015a):

- relative share per window type in the EU28 stock (Table 90, p. 111),
- the EU28 floor area (Table 185, p. 225) – 21.6 Mio m$^2$ residential

- the EU28 window-to-floor-ratio of 20% which is assumed in the report for residential buildings (Table 188, p. 228).

*Results for residential façade buildings, Task 7 estimate*
The result is an area of about 4.3 billion $m^2$ of façade windows in EU28. Although we've taken the numbers from Task 7 report, this is about 5% above the 4.1 billion $m^2$ indicated in Table 85. We were not able to find an explanation for this difference. As the window area significantly impacts the estimation of savings potentials through window improvements we'd welcome a clarification on the resulting range of 4.1 to 4.3 billion $m^2$.

*Ecofys estimate*
Unfortunately there are no precise statistics about the EU28 window area. For this reason we compared Task 7 window area estimates with numbers Ecofys have estimated e.g. for our study "Renovation Tracks for Europe up to 2050". (Boermans et al. 2012) and more recent research.

For 2010 we estimate the residential heated floor area to be about 18.5 billion $m^2$, of which about 59% is in Single-Family Homes (SFH) and 41% in Multi-Family Homes (MFH), the corresponding floor areas being about 10.9 billion $m^2$ and 7.6 billion $m^2$. From the TABULA database we assume 20% to be a realistic window-to-heated floor ratio for SFH and 15% for MFH. This results in 2.2 billion $m^2$ window area in SFH and about 1.1 billion $m^2$ in MFH. Thus our rough estimate of the total façade window area in the EU28 residential building stock is about 3.3 billion $m^2$. This number is to be compared with the range of 4.1 to 4.3 billion $m^2$ in Task 7 report.

**Finding 1**
We estimate a total heated floor area of about 18.5 billion m² and a total window area of about 3.3 billion m² for residential buildings. The corresponding values from Task 7 report are 21.6 billion m² floor area and a range of 4.1 to 4.3 billion m² window area. This means we estimate about 22% less overall window area in EU 28 residential buildings than the authors of Task 7 report. As there are significant uncertainties in building stock data, this is certainly due to different assumptions and maybe definitions. Still the gap is not negligible as our estimate would suggest a significantly smaller windows area that could benefit from an energy label. Therefore, as these numbers are essential for the BAU scenario and potential savings, we think it would be beneficial to discuss them with stakeholders.

**Heating energy for windows**

We also tried to replicate the calculation of *heating energy* for residential windows in BAU (Table 85). Unfortunately the Task 7 report does not provide a detailed allocation of the 11 window types to the climate zones, which we see as a major piece of missing information in the report. Would this information be available, each of the 11 windows differentiated by climate zone could be multiplied with their climate specific energy performance (Table 42, p. 97), which would result in the EU28 energy *need* for residential windows. Divided by the heating system efficiency this results in delivered (final) energy for windows. In Task 7 report an extraordinarily low heating system efficiency of 58.6% is assumed for each EU MS (Table 196, p. 231).

**Finding 2**
- We find 642 TWh heating energy[1] for residential façade windows in 2010 given in Task 7 report to be overestimated. Our estimate suggests 419 TWh, which is 35% below that number.
- When taking into consideration real life conditions like shading by trees and neighbour buildings, which we could not find has been considered in Task 7 report, window performance decreases and thus heating energy increases again to about 503 TWh. This still is 22% less than 642 TWh assumed in Task 7.
- This means that we estimate the savings potential of windows to be significantly lower than in Task 7 report, which also means that additional savings of an EU energy label are most probably overestimated as well.

Explanation:

- In Task 7 report 642 TWh seems to be the energy input into heating systems with an efficiency of 58.6% which is needed to compensate for net window energy losses. Yet, we estimate heating

[1] This is provided we understand correctly that 642 TWh "heating energy" stands for delivered energy for use in heating systems.

efficiency to be at least 70% as an EU average. This results in only 84% energy input into the heating system compared to Task 7 – leaving Task 7 window area unchanged => 537 TWh.

- Our estimate of the total relevant residential window area is roughly *78%* of Task 7 estimate. Multiplied with the heating system input mentioned before this results in 419 TWh of heating energy – which is 35% less than 642 TWh.
- Further corrections could come from differences in distribution of window types to buildings and climate zones and different results as to the performance of the assumed 11 window types in their real life situation.
    - We acknowledge the immense effort the authors of Task 7 report did to provide a proper estimation of the window shares across countries and climates. Although we guess that window types 1 & 2 (single glazing, simple double glazing) have a share of less than 60% across Europe's window stock in 2010, we do not dare to suggest corrections without very thorough own analysis.
    - According to our analysis in chapter 3, we deem the window energy performance values in Task 7 report (Table 42) to be too optimistic due to non-consideration of real-life conditions like shading by trees and neighbour buildings. As window types like 1 (single glazing) & 2 (simple double glazing) - where shading has a *relatively* low impact on the window energy performance[2] - are assumed to still dominate in 2010's window stock we estimate a supplement of (only) *20%* to the performance assumed in Task 7 report. This again would increase the heating energy from above mentioned 419 TWh to about 503 TWh, which still is 22% below Task 7 heating energy of 642 TWh for 2010.

[2] The more weight energy gains have in the overall window balance, the higher the relative change in window performance due to shading; therefore the *relative* performance loss of high efficiency windows is higher than with low efficiency windows.

**Finding 3**
As due to time constraints we were not able to validate numbers in Task 7 report for future energy used for space heating in buildings, we'd like to note two observations:

- we are sure there will be much better performing windows relative to theoretical energy *need* than today. Already today there are significantly better windows on the market (see also chapter 3) than the best ones assumed in Task 7 report; yet this theoretical advantage in practice is partly eaten up by real life conditions like shading and rebound effects, e.g. increased indoor air temperature with better performing windows.[3]
- savings of delivered energy by replacement of windows in the building stock will be eaten up to a significant extent by more and more efficient heating systems. After replacing an inefficient boiler there is much less left to save by a window replacement.[4] Certainly both developments will run in parallel till 2050. For this reason we'd very much like to know the heating system efficiency development till 2050 assumed in the Task 7 scenarios, as this very much influences the fuel savings that can be assigned to better windows. We could not find them.

**Heating energy of building stock**

Finally, the overall heat demand (delivered energy) of the residential and non-residential sector for EU28 provided in Task 7 has been validated by literature research. From our project "Renovation Tracks for Europe up to 2050" we found approximately 3,000 TWh delivered energy for space heating for both residential and non-residential buildings, having a ratio of approximately 3:1 (Boermans et al. 2012). This leads to about 2,250 TWh for residential and 750 TWh for non-residential buildings for 2012.
From Task 7 report we were unsure how to determine the heating demand in residential stock. While from Table 85 numbers it seems 2,675 TWh for 2012 can be derived, Table 192 explicitly states 1,800 TWh for residential buildings and 1,320 TWh for non-residential buildings.[5]

**Finding 4**
Our estimates of delivered energy for space heating do not match Task 7 numbers. From the numbers provided in Task 7 Annex it seems those numbers are about 20% below our estimate for residential buildings. As this is the basis for determining the important share of windows in overall building energy consumption we would welcome some more explanations on how Task 7 numbers have been estimated.

[3] A typical rebound effect is that average indoor air temperature during heating season will probably increase after replacement of old windows by new very efficient ones.
[4] Just imagine the stock of 58.6% efficient heating systems assumed in Task 7 to be replaced by boilers with 95% efficiency: this alone reduces the 642 TWh fuel consumption of windows given in Task 7 report, Table 85 to 398 TWh – without replacing a single window!
[5] 642 TWh/24% = 2,675 TWh, where in Table 85 642 TWh is "heating energy" and 24% is "share window heat loss of heat demand"; we couldn't find explanations in Task 7 report about the exact meaning/definition of these terms so we need to guess the meaning.

**Relative savings in Task 7 report scenarios**

Due to time restrictions we did not set up own scenario calculations. Thus we interpret the existing numbers given in Task 7 report, which are also cited in the draft Implementing Measure and Explanatory Memorandum.

Actually the *BAU* scenario suggests a *91% reduction* of heating energy for windows between 2010 and 2050 in residential buildings.[6] [As pointed out before we estimate the *absolute* savings potential to be lower than in Task 7 report.] While Table 85 mentions a "share window heat loss of heat demand" of 24% in 2010 this decreases to 15% by 2020 and 6% by 2050. Thus window energy performance improvements seem to be assumed to happen much faster than energy improvements of other building parts. [7] No more details are given about the development of other building components that affect the energy efficiency of the building.

As to non-residential buildings from Table 86 a reduction of 79% follows.[8]

Altogether the BAU scenario in Task 7 assumes a reduction of 89%[9] for the sum of residential and non-residential windows, i.e. *without considering the introduction of an energy label for windows.*

As overarching EU energy efficiency targets are about primary energy, the primary energy reductions for the use of windows given in Tables 85 and 86 are especially important.[10] Unfortunately primary energy factors and their development till 2050 are not explicitly documented. The numbers provided create the impression that a constant primary energy factor of 1.0 has been used between 1990 and 2050 which obviously would be unrealistic.[11] In any case in the report shares and relative decrease of primary energy are identical with the ones above for heating energy.

A constant primary energy factor suggests constant GHG emission factors. Nevertheless the numbers from Tables 85 and 86 reveal an emission factor of 199 g $CO_2$/kWh fuel for 1990 which gradually falls to 168 g $CO_2$/kWh fuel by 2050. In parallel an absolute growth in "cooling energy" is stated for the

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[6] (642 TWh_fuel – 58.9 TWh_fuel)/642 TWh_fuel = 91 %.

[7] Of course energy consumption due to non-window related efficiency improvements decrease as well between 2010 and 2050. Therefore a constant share of 24% for residential windows in residential building energy consumption would mean window efficiency improvements having the same speed as improvements of non-window parts.

[8] (80 TWh_fuel – 17.1 TWh_fuel)/80 TWh_fuel = 79 %.

[9] (642 TWh – 58.9 TWh + 80 Twh – 17.1 TWh) / (642 TWh + 80 TWh) = 89%.

[10] According to the definition in Draft prEN ISO/WD 52000-1:2015[10] "primary energy" is "energy that has not been subjected to any conversion or transformation process", i.e. as usually there are several conversions or transformations between the original energy source (e.g. coal mine) and the final consumer (e.g. electricity) the losses in between are accounted for by means of the so-called primary energy factor (PEF). It should be differentiated between the renewable, non-renewable and total primary energy factor. Tables 85 and 86 in the Task 7 report do not specify the kind of primary energy. In this case usually total primary energy or non-renewable primary energy is spoken of, which are identical as long as no renewable energy is involved. ISO/WD 52000-1:2015 gives some default values for total PEFs, e.g.: all solid, liquid and gaseous non-renewable energy carriers: 1.1; district heating and cooling: 1.3; grid electricity: 2.5 (2.3 non-ren; 0.2 ren); on-site PV, wind, solar-thermal: 1.0 (0.0 non-ren; 1.0 ren). The PEF for space heat obviously needs to be a mix of these factors to reflect reality of having a mix of different energy carriers used for space heating. Moreover, it is clear that this mix will change between 2010 and 2050 towards a higher share of renewable primary energy.

[11] Only there is a constant factor of 3.6 between "*final* energy (TWh_fuel/yr)" and "final energy (PJ_*prim*)" (Tables 85/86). This is just reflecting the equivalence of 1 TWh and 3.6 PJ without any further factor in between.

sum of residential and non-residential windows. This results in 88% $CO_2$ emissions reduction between 2010 and 2050.

**Finding 5**
Although the authors have provided a lot of information, Task 7 report does not allow to reproduce the numbers of the BAU scenario (e.g. the *91% reduction* of heating energy for residential windows between 2010 and 2050) which is due to some missing data, e.g. details about the assumed window stock, and to the use of terms with unclear meaning. As the BAU scenario is the reference for evaluating the potential additional savings of a window energy label, this is a pity. Therefore, in order to enable discussions on potential additional savings of a window energy label on a level playing field, we would appreciate the provision of missing information and explanations. Obviously the authors have put an enormous effort in Task 7 report. Therefore we assume this information to be available.

**Finding 6**
As to criterion a) "Significant potential for saving energy" of the Energy Labelling Directive, which needs to be fulfilled for eligibility of an energy related product for an energy label we can safely say that – even considering our reservations about the numbers of the preparatory study - this criterion is met in the case of windows. Yet, in the context of an energy label the decisive question is to what extent additional measures beyond BAU like an energy label will actually mobilise additional savings for products having a significant potential for saving energy. This question will be dealt with below.

The BAU scenario presents the expected development without any further additional measures being added to EU and MS regulations which are already in place and certainly exert a significant drive towards more efficient windows like the EPBD, EED (Energy Efficiency Directive) and their national implications. In the BAU scenario, i.e. *without the introduction of an energy saving label,* huge savings of about 90% *only between 2010 and 2050* are estimated. Please compare with long-term EU climate targets as communicated in "A roadmap for moving to a low carbon economy" (European Commission (EC) 2011), where an 88%–91% reduction target for the building sector is given for the period *1990*–2050. Accordingly, starting with the 1990 numbers of Task 7 report (Table 85) for the residential BAU scenario results in 95.5% savings of windows' "heating energy", 93.2% of "heating + cooling energy" and 94.3% of GHG emissions.[12]

The question is at hand, whether an energy label can have a relevant *additional* benefit.

[12] As windows do not only have losses but also have energy gains – in contrast to opaque building elements like walls and roofs– windows may provide *net* energy gains to the building. Within this logic, even savings of more than 100% from windows alone might be possible, as can be seen in the "Advanced" and "Extreme" scenarios presented in Task 7 report, where the windows stock provides small net energy gains during the heating season.

Task 7 report analyses three different scenarios for the impact of an EU window energy label: modest, advanced and extreme. Taking the residential „Advanced Scenario" as the average, 64.3 TWh savings of "heating energy" compared to BAU are estimated.[13] This equals 10% (4.9%) of residential windows' 2010 (1990) energy balance or roughly 3.6% of total residential heating energy in 2010 due to the impact assigned to the energy label.[14] Remember that due to different effects described above, we assume that 64.3 TWh is too high.

What we found very remarkable in comparing the numbers of "BAU, Moderate, Advanced and Extreme" residential scenarios are the numbers for "cooling energy": while in BAU between 2010 and 2050 there is a rise from 21 to 30 TWh, in "Modest" the rise stops at 26.9 TWh, in "Advanced" at 26.5 TWh and in "Extreme" at "26.0". Compared to the savings envisaged for heating energy this is in the range of 1%. It is discussed that "cooling performance" should be presented on an energy label for windows as well. Considering the minute savings of cooling energy that have been assumed for this measure in the scenarios it seems to be very questionable whether addressing "cooling energy performance" in a window energy label which is to specifically address small scale replacements of residential façade windows is an efficient approach.

**Finding 7**
The additional savings for space heating of an energy label compared to the BAU scenario even in the "Extreme" scenario of Task 7 report appear to be low. As we assume the numbers for energy consumption of windows in BAU to be too high as well as due to rebound effects and improving efficiency of heating systems, we assume these small savings in reality will be even lower.

**Finding 8**
In the Scenarios, savings for cooling energy achieved *by the introduction of an energy label* are between 3 to 4 TWh, compared to 33 to 99 TWh for heating energy. We acknowledge overheating may be a problem in badly designed nearly-zero energy buildings (NZEB)– but then this probably needs to be addressed by a more holistic approach than with an energy label which according to the Explanatory Memorandum is aiming at small scale residential window replacements where the problem of overheating is not very probable to arise.

[13] We estimate the BAU numbers to be too high. Therefore savings given in "energy label scenarios" potentially are too high as well.
[14] "Heating demand" residential 2010 according to Table 192: 1,800 TWh; according to Table 85: Residential „heating energy" 2010: 642 TWh / 24% „share window heat loss of heat demand" = 2675 TWh. Table 85: Residential „heating energy" 1990: 1308 TWh / 37% „share window heat loss of heat demand" = 3535 TWh (cf. Task 7 report, Table 85). As there are no numbers for a share of window energy loss in heat + cold demand we restrict this to heating energy.

### 2.1.2 Criterion b) Wide disparity in the relevant performance levels

As to criterion b) "Wide disparity in the relevant performance levels", two aspects seem to be relevant:

- What is the actual disparity of relevant performance levels? This question will be answered in chapter 3 based on a large number of calculation results.
- Is the energy *use* which is covered under the energy label still the only relevant performance information? Does inclusion of Life-cycle-assessment information (production, end of life) change the picture?

**Table 1. Proposed Windows Energy Label Classes (heating only); taken from draft delegated regulation**

| | Facade windows and window doors ($kWh/m^2$) | | |
|---|---|---|---|
| **Class** | North | Central | South |
| **A** | P≤-27 | P≤-50 | P≤-99 |
| **B** | -27<P≤-14 | -50<P≤-37 | -99<P≤-87 |
| **C** | -14<P≤-1 | -37<P≤-24 | -87<P≤-75 |
| **D** | -1<P≤12 | -24<P≤-11 | -75<P≤-64 |
| **E** | 12<P≤25 | -11<P≤3 | -64<P≤-52 |
| **F** | 25<P≤39 | 3<P≤16 | -52<P≤-41 |
| **G** | P>39 | P>16 | P>-41 |

**Table 2. Proposed Energy Label Classes assigned to preparatory study façade windows**

| | $U_w/g$ | | North | | Central | | South |
|---|---|---|---|---|---|---|---|
| 1 | 5.8/0.85 | G | 588 | G | 340 | G | 14 |
| 2 | 2.8/0.78 | G | 193 | G | 88 | D | -64 |
| 3 | 1.7/0.65 | G | 71 | F | 16 | D | -74 |
| 4 | 1.3/0.6 | F | 39 | E | -3 | D | -74 |
| 5 | 1/0.55 | E | 17 | D | -14 | D | -72 |
| 6 | 0.8/0.6 | C | -13 | C | -36 | C | -85 |
| 7 | 1/0.58 | D | 11 | D | -19 | C | -77 |
| 8 | 0.6/0.47 | C | -9 | C | -28 | D | -67 |
| 9 | 2.8/0.35 | G | 273 | G | 160 | G | 13 |
| 10 | 1.3/0.35 | G | 85 | G | 39 | G | -29 |
| 11 | 0.8/0.35 | F | 34 | F | 6 | F | -41 |

As Table 1 shows, which is taken from the proposed delegated regulation (European Commission (EC) 2015b), heating class boundaries have been tightened significantly compared to a proposal made in Task 7 report (van Elburg et al. 2015a, p. 79, Table 43).
According to a potential requirement in the upcoming Energy Labelling Directive, Best Available Technology (BAT) is put into class C, while classes A and B remain empty in order to leave room for future improved windows. In Table 2 we have assigned the 11 window types analysed in the preparatory study to the heating classes. The best windows are numbers 4, 5, 6, 7 and 8 – as to more details on these windows please also see Table 3 on page 22. These are all windows with at least three panes and the only ones having a net energy surplus during use.[15] All those windows have higher primary energy input for production/distribution/end of life than during use. In case of windows 5, 6, 7 there are net gains during use, thus improving the life-cycle primary energy balance.

Figure 1 taken from Task 5 report (van Elburg et al. 2015b) reveals a clear tendency of those windows being most efficient during use that have the highest primary energy need for production. While this is not very surprising, the new situation is, that according to (Molenbroek et al. 2013, p. 74) so far most preparatory Ecodesign studies showed that typically more than 90% of the life-cycle impact take place during the use phase. But in the case of BAT windows both energy needed during use and production are close to each other. Therefore care needs to be taken to not add more energy during production than what can be saved additionally afterwards during use, especially considering real life use rather than laboratory values. Generally the optimization of energy in use should not be bought by increasing energy needed during the whole life-cycle (Molenbroek et al. 2013, p. 79).

Figure 1 shows that especially for windows 4 (double-glazing), 5, 7 (triple glazing) and 8 (two-times double glazing) it is questionable whether the very small differences in the overall life-cycle balance qualify to be called a "wide disparity". While in energy use there is a difference of about 4,600 MJ primary energy, this melts down to about 2,900 MJ when considering the whole life-cycle. This is just about the amount needed to produce window 7.

[15] This changes when shading by trees, surrounding buildings etc. is assumed, see chapter 3.

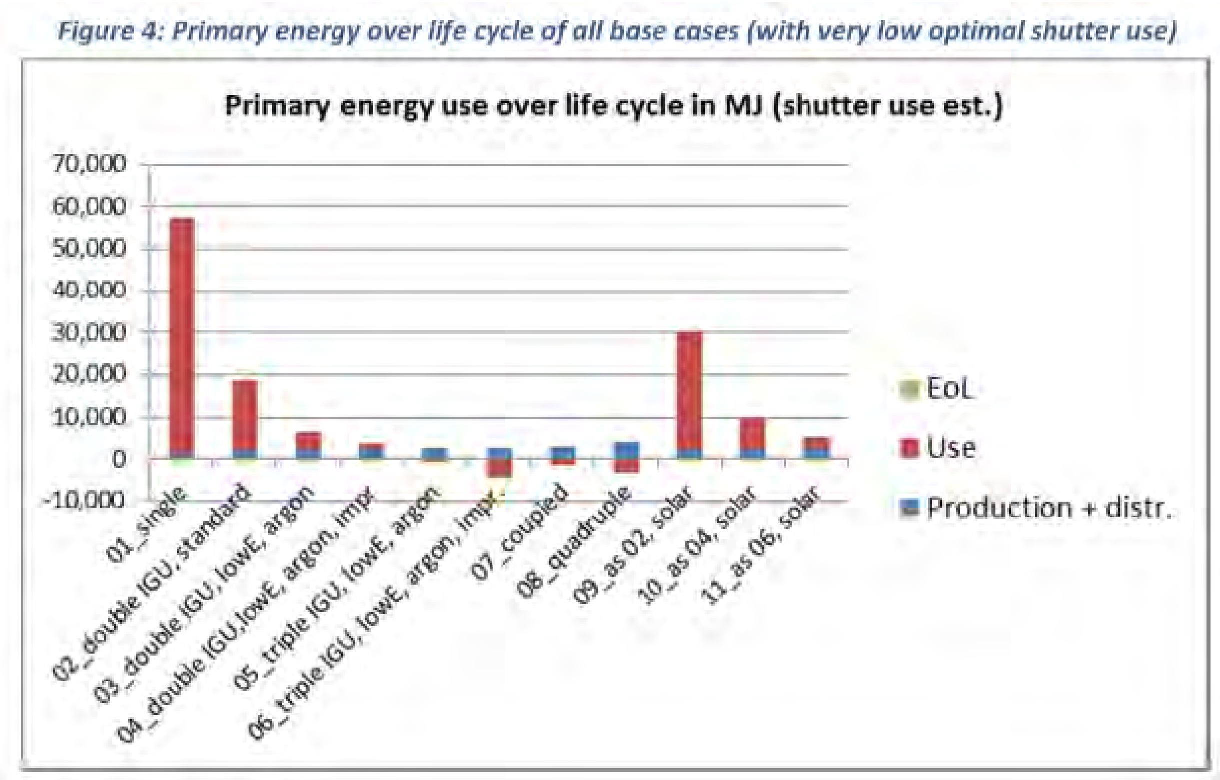



**Figure 1. Primary energy use over life cycle for different windows**

**Finding 9**

The proposed energy label class boundaries rank those windows best which at the same time tend to have the highest production impact. Care needs to be taken that additional (real) energy savings during use are not overcompensated by additional (real) energy input during production. In any case savings in use are partly compensated by increased primary energy input for production. Table 10, Task 5 report e.g. shows that 24% of advantage in energy use between window 4 (double) and 5 (triple) is "eaten up" again by additional energy input in the other phases. For going from window 5 (triple) to 7 even 48% are eaten up again. In real-life situations this advantage may completely melt away or even go to negative numbers. Of course this also means that the net primary energy savings that have been calculated for the energy label need to be corrected by the additional primary energy use caused by potentially more material intensive window types. Without detailed analysis we are not able to give a precise estimation, but judging from the two examples another reduction of the window energy savings potential of at least between 20-40% doesn't seem to be unrealistic.

Designing the label as proposed with an "in-use-only" focus will clearly support a competition about the best energy balance in use instead of promoting the best life-cycle energy balance. While this is fine for products where the bulk of life-cycle impact is generated during use, in case of very efficient windows which are to be promoted by the label, this may trigger similar cases of sub-optimisation as the previous focus on U-value has produced.

It must be emphasized that this is a new aspect which has not been relevant until recently when energy during use clearly dominated the life-cycle impact. As we expect a major impact of an EU windows energy label on manufacturers, we think it to be a likely consequence that in the race for the most energy efficient window in use manufacturers will sub-optimize their windows according to best possible "energy label performance" rather than best possible life-cycle performance, hence increasing total primary energy consumption. This is another reason to very carefully assess the savings that can actually be achieved in a real life context.

### 2.1.3 Criterion c) Relevant Union legislation and self-regulation

The EPBD and its recast are to trigger significant improvements of the energy performance of new and existing buildings. Specifically two requirements of the EPBD require action from Member States towards more efficient buildings:

- The requirement to determine minimum energy performance requirements in building codes based on a life-cycle based cost-optimality approach.
- The requirement to introduce "nearly zero energy buildings" by 2019 (new public buildings) or 2021 respectively (all other new buildings) and to develop plans on how to increase the number of nearly zero-energy buildings also in the building stock.

As only during 2013 and 2014 all MS have implemented the recast EPBD, now the impact of these two new requirements will start to get visible on the markets. By experience clear requirements in building codes have a strong impact on the market of construction products. A recent study of (Manteuffel et al. 2014) demonstrated innovation and market price decreases triggered by tightening of the building code requirements in Germany. The study was commissioned as in Germany there is a lot of discussion whether building codes move the bar up too fast and cause unacceptable increase in construction costs.
In fact, from all building elements analysed, façade windows showed the highest speed of innovation. The graph shows U-value requirements which have been in the building codes since 1990 or which de facto are applied in order to meet whole building energy performance requirements. Prices shown are valid for new construction, they tend to be a bit higher in renovation. Experience in Germany shows that each new building code version quickly led to a phase out of the previous window generation. The moment a new building code was in place, the real price of the windows usually was equal to the real price of the previous generation. There is also no market for inferior "renovation window" qualities. Figure 2 also shows window qualities related to the standards "KfW EH 40", which may be assumed as being close to the yet unknown German nearly zero energy buildings requirements, as well as Passive House standard. In both triple-glazed windows are used.
This development is mainly driven by building code requirements but also by the KfW (German Bank for Reconstruction) programs which generally subsidize the "next generation" building elements or buildings.

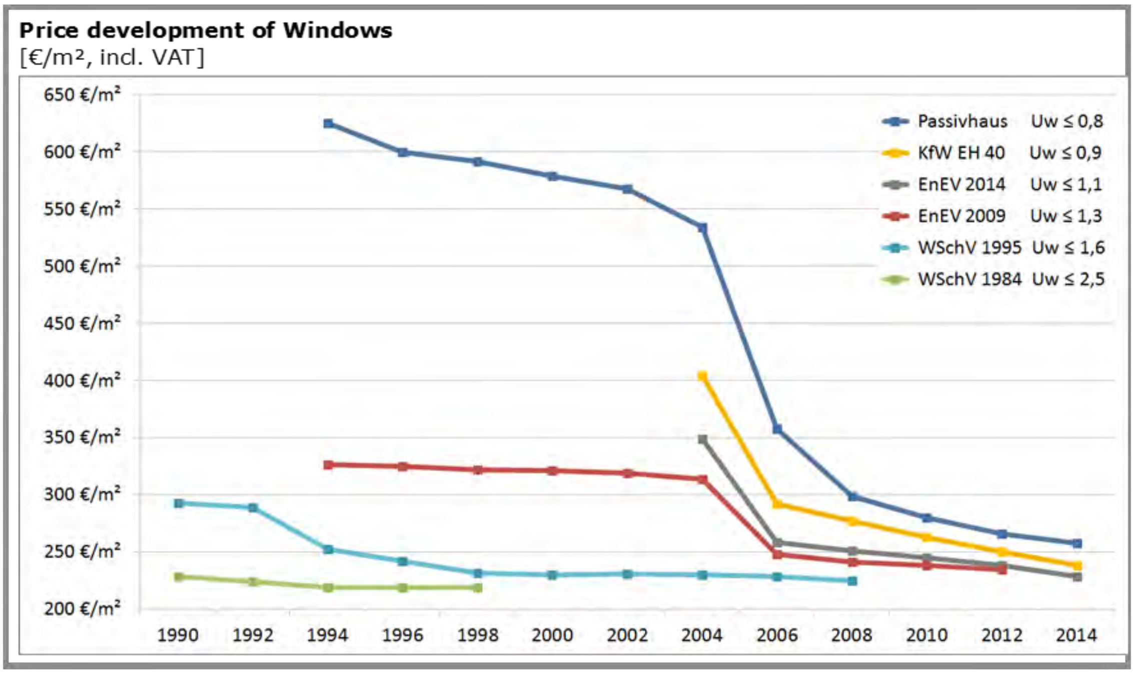



**Figure 2. Window (real 2014) prices (installed) in Germany for window qualities related to different building standards**

Taking the German example it is questionable to what extent a window energy label realistically may go beyond a "Business as Usual"-Scenario, which already includes the push caused by cost-optimality and nearly-zero-energy building requirements.

**Finding 10**

Strict building code requirements which MS set up with a view to cost-optimal minimum energy performance requirements and nearly-zero energy buildings inevitably need to drive improved window energy performance. This is because the energy performance of low energy buildings "lives and dies" with windows' impact on the overall building energy performance. For example in a typical Passive House windows may easily both supply the largest share of (solar) heat (even bigger than heating system share) while at the same time being the building component with the highest losses.[16]

*Current MS requirements on windows*

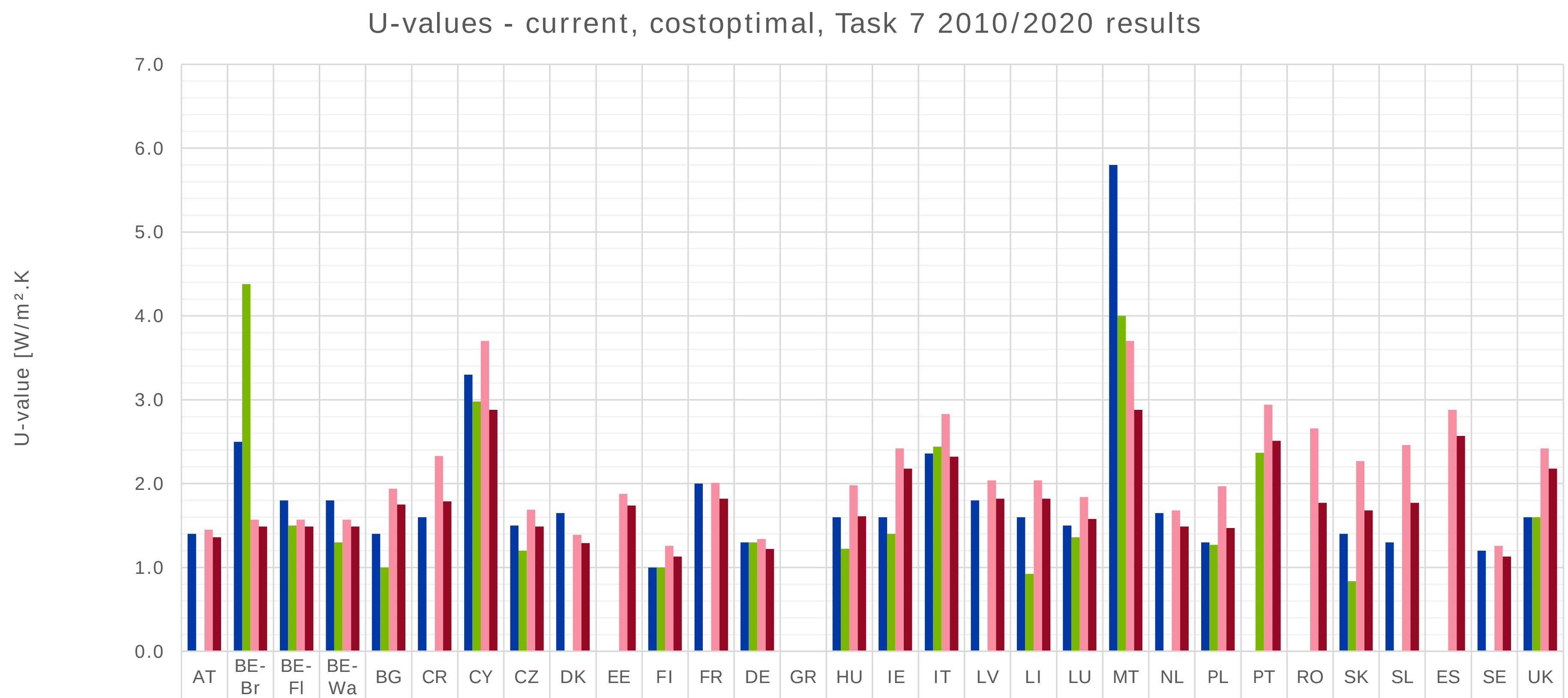
In order to get an overview about current and potential future requirements for windows across EU MS with a view to cost-optimality and nearly-zero energy buildings we analysed

[16] An example for this prominent role of windows is e.g. included in the Excel-spreadsheet "Passive House Project Package (PHPP) v 9.2.

- All available MS Cost-Optimality reports[17]. These reports in many cases provide information about current U-values of windows and cost-optimal U-values of windows. As MS are to adapt current requirements to potentially more ambitious requirements, it can be assumed that in these cases U-values will be adapted at least once, until another potential update with the introduction of nearly-zero energy buildings.
- The EPBD Concerted Action reports from 2012. The book provides comprehensive information about the status of EPBD implementation in all EU Member States by early 2013. Latest developments are not included. Still the reports provide additional information about U-values in place by 2012, partly for 2014 and rarely for 2020. The next reports are expected for November 2015. They will most probably provide most valuable information about MS next steps towards 2020, including outlooks for requirements on windows.

The result of this analysis is presented in Figure 3. In order to compare with 2010 and 2020 numbers used in Task 7 report of the windows preparatory study, we included the average U-values used in the BAU scenario (Table 199) as well.

[17] available at http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings




| | AT | BE-Br | BE-Fl | BE-Wa | BG | CR | CY | CZ | DK | EE | FI | FR | DE | GR | HU | IE | IT | LV | LI | LU | MT | NL | PL | PT | RO | SK | SL | ES | SE | UK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U_current | 1.4 | 2.5 | 1.8 | 1.8 | 1.4 | 1.6 | 3.3 | 1.5 | 1.7 | | 1.0 | 2.0 | 1.3 | | 1.6 | 1.6 | 2.4 | 1.8 | 1.6 | 1.5 | 5.8 | 1.7 | 1.3 | | | 1.4 | 1.3 | | 1.2 | 1.6 |
| U_costopt | | 4.4 | 1.5 | 1.3 | 1.0 | | 3.0 | 1.2 | | | 1.0 | | 1.3 | | 1.2 | 1.4 | 2.4 | | 0.9 | 1.4 | 4.0 | | 1.3 | 2.4 | | 0.8 | | | | 1.6 |
| U_Task7_2010 | 1.5 | 1.6 | 1.6 | 1.6 | 1.9 | 2.3 | 3.7 | 1.7 | 1.4 | 1.9 | 1.3 | 2.0 | 1.3 | | 2.0 | 2.4 | 2.8 | 2.0 | 2.0 | 1.8 | 3.7 | 1.7 | 2.0 | 2.9 | 2.7 | 2.3 | 2.5 | 2.9 | 1.3 | 2.4 |
| U_Task7_2020 | 1.4 | 1.5 | 1.5 | 1.5 | 1.8 | 1.8 | 2.9 | 1.5 | 1.3 | 1.7 | 1.1 | 1.8 | 1.2 | | 1.6 | 2.2 | 2.3 | 1.8 | 1.8 | 1.6 | 2.9 | 1.5 | 1.5 | 2.5 | 1.8 | 1.7 | 1.8 | 2.6 | 1.1 | 2.2 |

**Figure 3. U-value requirements across Europe**

Our analysis of cost-optimality reports proved that in many MS there is room for improving current (2012/2014) U-value requirements to cost-optimal levels. As cost-optimal calculations were performed in 2012/13 it can be expected that MS will adapt their window requirements soon or already did so; for example Poland in the meantime set up much stricter requirements.
When we weigh U-values presented in Figure 3 with sales volumes given in window preparatory study Task 5 report we arrive at the following results:

- The average U-value assumed in Task 7 report for 2010 is 2.04 W/m$^2$K.
- The average U-value assumed in Task 7 report for 2020 is 1.77 W/m$^2$K.
- The average U-value today (from cost-optimality reports) is 1.79 W/m$^2$K.
- The average U-value which was deemed to be cost-optimal in 2012 and actual values already in place today is 1.72 W/m$^2$K.

As cost-optimal values have been determined by MS in 2012/13, considering the innovation and real price decrease presented in Figure 2 we can safely assume that actual sales-weighted U-values by 2020 will be lower than 1.72 W/m$^2$K. The next cost-optimality round will determine U-values for 2020. Consequently it must be expected that cost-optimal calculations for 2020 will lead to significantly higher performing windows, not to forget the additional push caused by nearly-zero energy buildings. Therefore our estimate for average U-values by 2020 is max. U = 1.6 W/m$^2$K as a European average, while Task 7 report quite conservatively assumes 1.8 W/m$^2$K for 2020 in the BAU scenario.[18]

**Finding 11**
Due to the results of cost-optimal calculations, the need to provide the next cost-optimality report by 30. June 2017, NZEB reports by 31. December 2015 and 31 December 2018 and nearly-zero energy buildings being mandatory by 2019/2021, we assume this will significantly push building code requirements and – being *the* crucial element for building performance – automatically MS window energy performance requirements as well. Compared to the BAU average U-value of 1.8 W/m$^2$K we expect a sales weighted average U = 1.6 W/m$^2$K and thus windows which perform better than assumed in the Business-As-Usual (BAU) scenario for 2020. This is what is assumed in the Task 7 BAU scenario for the year 2040 – and thus reduces the additional savings a window energy label could have.

Criterion No. 3 of Article 10 Energy Labelling Directive is also about the additional burden an energy label would put on top of existing regulation or compared to voluntary agreements. Task 7 report

[18] Most interesting is a look at Europe's biggest countries. Germany has not yet defined 2020 requirements; we expect a value of 1.1 W/m$^2$K or lower; already today a significant share of the window sales features triple-glazing. Similarly for Italy we expect 2020 below Task 7 assumptions. However, Italy as a Southern country, is not as critical for Europe's space heat consumption as France, with more floor area in the central climate region. U-values assumed for France in Task 7 report for us appear to be realistic. UK's requirements already today are significantly more demanding than Task 7 assumptions for 2020. Spain provided values for a number of climate zones; due to lack of time we were not able to calculate a weighted average that could be compared with Task 7 numbers. Therefore we just took the Task 7 values for our calculations. Finally Poland already today has significantly more demanding U-values than what has been assumed in Task 7 for 2020.

argues that the additional effort to calculate the energy performance of windows is limited or none as the information required for the calculation (cf. Table 4, Task 7 report) is in general available from the window manufacturer due to CE marking according to mandated window characteristics that are determined according to the harmonized European Standards EN 14351-1 (van Elburg et al. 2015a, p. 33).

- Generally mandated characteristics in EN 14351-1 are regulated in the building legislation of MS. When MS building regulation does not require e.g. U-value and/or g-value and/or air permeability then this value won't be readily available from the DoP. In fact this is partly the case, which is also acknowledged by the explanatory memorandum (European Commission (EC) 2015a, p. 4)
- From a brief check of actual window CE marks, we found that in fact in many countries U- and g-values are provided (the latter not necessarily on the window CE marking but on the glazing CE marking), yet there are countries like the UK where the air-permeability class of the window is not provided.

| |
|---|
| **Thistle Windows & Conservatories Ltd.**<br>**Unit A, Woodside Road, Denmore Industrial Estate, Bridge of Don, Aberdeen, UK**<br>**AB23 8EF**<br><br>**13**<br><br>**DoP No: 1- 28/06/13**<br><br>**For Traceability Refer to Product Label**<br><br>**VEKA Matrix 70mm Window and Door System,**<br>**Intended for use in domestic or commercial refurbishment or new building applications (doors not on escape routes).** |
| **Annex ZA.1 of BS EN 14351-1:2006+A1:2010**<br>**Watertightness: NPD**<br>**Dangerous substances: None released under normal indoor use.**<br>**Resistance to wind load: NPD**<br>**Load-bearing capacity of safety devices: Pass, 350N when fitted (1)**<br>**Acoustic performance: NPD**<br>**Thermal transmittance:No worse than 1.6W/$m^2$k (2)**<br>**Radiation Properties: NPD**<br>**Air permeability: NPD** |

**Figure 4. Example of UK window CE marking and DoP.**

The example from UK (Figure 4) shows that manufacturers are not obliged to declare the air permeability performance of their products. Concretely from the 23 performance characteristics listed in EN14351-1, according to UK building regulations only "Thermal Transmittance", "Load Bearing Capacity of Safety Devices", "Dangerous Substances" and "Ability to Release" need to be declared [BRE 2015]. Similarly even thermal transmittance may not be regulated in some MS (or candidates like Turkey where CE mark only requires load bearing information). Of course it may be possible that manufacturers declare such performance characteristics on a voluntary basis even if there are no national regulations in place. It's also possible to calculate energy performance assuming the worst air permeability class in the absence of declared value. Nevertheless our calculations showed that e.g. assuming air permeability class 2 or 3 instead of 4 significantly downgrades energy performance.

**Finding 12**
Many window manufacturers across the EU would face a significant burden to provide for the air permeability class which is needed for the calculation of the window energy performance, cf. (European Commission (EC) 2015b, p. 22, Annex VIII, equations 2 and 5). Other parameters needed for the energy performance calculation may not readily available from CE marking as well in each MS. Therefore we assume that especially for SME, the major producers of windows, calculating and issuing energy labels will in fact create a significant additional burden.

As Task 7 report states (van Elburg et al. 2015a, p. 147), "currently most suppliers supply data for the whole window, based on total window measurement or use of tabulated data …". According to EN 14531-1 U-value of window can be calculated using three different methods

> Simplified calculation using tables (EN 10077-1)
> Detailed calculation (EN 10077-2)
> Hot box measurement.

However literature (Specht 2003) provides evidence that the detailed calculation leads to lower U-values than the simplified method (using tabulated values). As this generally improves the window energy balance, consequently manufacturers would go for the detailed calculation – which needs significantly more effort, in order to avoid systematic disadvantages from the much cheaper simplified calculation. Therefore it seems to be probable, that an energy label would provide a systematic competitive advantage to those manufacturers who can afford to provide a detailed calculation, i.e. the same window might get different energy label ratings depending on the calculation method applied.

**Finding 13**
Using tabulated values for determining window energy performance with low effort may lead to a systematic distortion of window energy performance calculations towards worse performance. Therefore manufacturer who currently use tabulated values might be forced to go for much more expensive detailed calculations in order to avoid competitive disadvantages due to different classification of identical windows due to using different calculation methods. This is counterproductive as energy labels should impartially promote products having objectively the better energy performance.

*Energy labelling vs. Ecodesign vs. CPR*
During the preparatory study there has been some discussion on what would be the best approach to exploit the savings potential of windows. Without getting into the details provided in the very comprehensive preparatory study reports, even the authors of the report obviously are not fully convinced about the potential success of an energy label for windows.

- "The effectiveness of an European energy label for windows is difficult to predict as only one of the labelling schemes in the EU provided some information on its effectiveness to transform the market, and this example (the UK WER scheme) is not considered representative. It is assumed that the success of the Label in the UK is also because the label is addressed in the British regulation as one option to show compliance with the requirements for domestic refurbishment." (van Elburg et al. 2015a, p. 22)
- In principle also Construction Products Regulation could result in a performance rating and label. The authors conclude: "The benefit, when compared to developing an EU label under 2010/30/EU, is unclear. …. As this study deals with the feasibility of establishing an EU Energy label for Windows, we will not further develop the above described approaches [like evolution of window CPR], as this is outside the scope of this study. It is the responsibility of the Commission to further develop such approaches when required." (van Elburg et al. 2015a, p. 69). The explanatory memorandum states that "An EU Energy Label would not interfere with the objectives and procedures set out by the CPR. On the contrary, both schemes can be seen as supporting each other (the CPR setting the rules for provision of performance data, the energy label conveying this data to consumers in a more meaningful way)." (European Commission (EC) 2015a, p. 3), which according to the Commission is because an energy label allows for a relative comparison and consumers lack the knowledge to judge the information given on the CE marking.
  We feel it to be a somewhat strange explanation to heal shortcomings of the non-appealing CE marking design, which in principle offers the possibility to provide useful information to the consumer in a meaningful way, by adding yet another label The US NFRC label provides a good example how CE marking could be designed in order to be meaningful for consumers.[19]
  In this context we'd like to note that the term "consumers" according to Energy Labelling Directive also includes professionals like building industry, craftsmen etc.

**Finding 14**
Task 7 report in an honest manner does not give a convincing explanation why an energy label should be preferable compared to e.g. providing more information thru exploiting the possibilities given by CPR. The proposed delegated regulation or the explanatory memorandum do not add strong arguments to that report.

[19] See also (van Elburg et al. 2015a, S. 103, footnote 57).

# 3 Review of the proposed energy performance rating system

## 3.1 Rebuild model SFH with Passive House Project Package

In a first step we rebuild the single family house of the Task 4 report (p. 28-30) for the purpose of validating the Task 7 report calculations with the Passive House Project Package (PHPP) by the Passive House Institute (Darmstadt, Germany).

*Geometry*

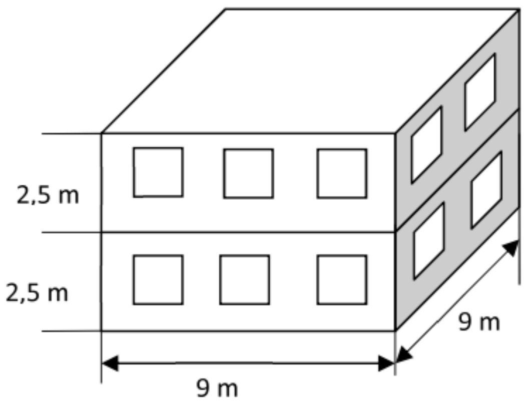



**Figure 5. Internal dimensions of simplified single family house**

As there is no further explanation given in Task 7 report, we assume that the dimensions shown in the Figure 5 above represent internal rather than external dimensions, leading to a corresponding floor area ($A_{floor}$ = 2 floors * (9 m * 9 m) = 162 m²) and air volume (V = 162 m² * 2.5 m = 405 m³) as indicated in Task 7. Additionally the climate conditions are used as indicated in the Task 4 report (p. 79):
A window area of 32.4 m² (20% * 162 m² = 32.4 m²) is considered which is equally distributed over the orientations (Task 4, p. 28). A frame fraction of 30% is considered (Task 4, p. 30).

- North = Helsinki,
- Central = Strasbourg,
- South = Athens.

*Ventilation, temperature setpoint and internal heat gains*
Furthermore in line with Task 4/7 reports we consider

- a ventilation rate of 0.5 1/hr
- an internal set point temperature of 20°C

- an internal load of 5 W/m² (Task 4, p. 29).

*Thermal quality of building elements*

The $U_w$- and g-values and the air tightness classes (and their impacts on the window U-values) of the 11 windows of the Task 4 report (p. 25) are considered as well.

**Table 3. Uw- and g-values, air tightness classes and descriptions of the 11 window design options considered**

*Table 6: Façade windows design options*

| nr | Thermal transmittance $U_w$ in W/(m²K) | Solar energy transmittance of the glazing g | Class Air tightness | Technical description of the window |
|---|---|---|---|---|
| 1 | 5.8 | 0.85 | 2 (27m³/(h m²) at 100 Pa) | Single glazing<br>Frame: even no or bad thermal break |
| 2 | 2.8 | 0.78 | 3 (9m³/(h m²) at 100 Pa) | Double IGU<br>Standard frame (wood, PVC, Metal) |
| 3 | 1.7 | 0.65 | 4 (3m³/(h m²) at 100 Pa) | Double IGU with low e-coating and argon filling<br>Standard frame (wood, PVC, Metal) |
| 4 | 1.3 | 0.60 | 4 (3m³/(h m²) at 100 Pa) | Double IGU with optimized low e-coating and argon filling<br>Standard frame (wood, PVC, Metal) |
| 5 | 1.0 | 0.55 | 4 (3m³/(h m²) at 100 Pa) | Triple IGU with low e-coating and argon filling<br>Standard frame (wood, PVC, Metal) |
| 6 | 0.8 | 0.60 | 4 (3m³/(h m²) at 100 Pa) | Triple IGU with optimized low e-coating and argon filling, thermally improved spacer<br>Improved frame (wood, PVC, Metal) |
| 7 | 1.0 | 0.58 | 4 (3m³/(h m²) at 100 Pa) | Single and Double IGU with low e-coating and argon filling, thermally improved spacer<br>Coupled window(wood, PVC, Metal) |
| 8 | 0.6 | 0.47 | 4 (3m³/(h m²) at 100 Pa) | 2 Double IGU with low e-coating and argon filling, thermally improved spacer<br>Double window (wood, PVC, Metal) |
| 9 | 2.8 | 0.35 | 3 (9m³/(h m²) at 100 Pa) | Double IGU with solar control coating<br>Standard frame (wood, PVC, Metal) |
| 10 | 1.1 | 0.35 | 4 (3m³/(h m²) at 100 Pa) | Double IGU with solar control coating (also low e) and argon filling<br>Standard frame (wood, PVC, Metal) |
| 11 | 0.8 | 0.35 | 4 (3m³/(h m²) at 100 Pa) | Triple IGU with solar control coating (also low e) and argon filling, thermally improved spacer<br>Improved frame (wood, PVC, Metal) |



- We'd like to stress that even better window qualities than have been assumed in Task 7 report (see Table 3 in this report) are available on the market today, there will be significant room for improvement till 2050. As this is 35 years from now just imagine the progress that has been made in window technology since 1980 – without having an energy label for windows. Just to give an example the database of certified Passive House components already today features windows having $U_w$ = 0.6 W/m²K and g = 54% (triple glazing) which is significantly better than the quadruple (!) glazed window No. 8 in the preparatory study.

The following levels of insulation of the model SFH are considered in the Task 4 report.

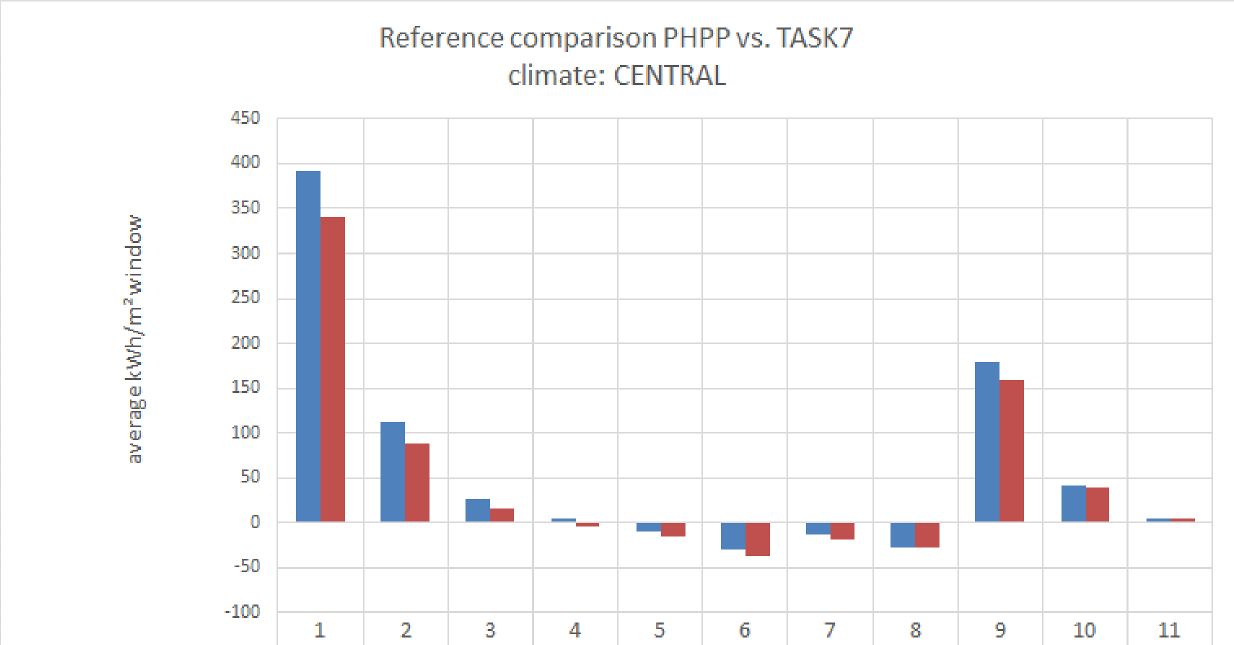
**Table 4. Levels of insulation simulated for the 3 climates**

| Climate | | Mean U-value of the opaque building envelope $\overline{U}_{env}$ in W/m²K |
|---|---|---|
| **North** | Single family house "old" | 0,6 |
| | Single family house "renovated" | 0,3 |
| **Central** | Single family house "old" | 0,8 |
| | Single family house "renovated" | 0,4 |
| **South** | Single family house "old" | 1,0 |
| | Single family house "renovated" | 0,6 |

For practical reasons only one mean U-value of the opaque building envelope of 0.6 W/m²K is considered in our own calculations per climate zone (North/Central/South).

## 3.2 Comparison of Passive House Project Package with Task 7 results for space heating

The figure below shows the comparison between the Task 7 and PHPP results for the average values of the heating performance in kWh/m²window as an average over the four orientations. Reference values were taken from Table 20 in Task 7 report derived from window specific ABC-values. Numbers 1-11 in all subsequent figures and tables correspond to the window numbers in Task 7 report, also compare Table 3.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_CENTRAL_REF | 392 | 112 | 28 | 6 | -9 | -30 | -13 | -28 | 180 | 42 | 5 |
| TASK7_CENTRAL_REF | 340 | 88 | 16 | -3 | -14 | -36 | -19 | -28 | 160 | 39 | 6 |

**Figure 6. Comparison of window performance PHPP vs. Task 7, Central, Reference comparison, kWh/m²window**

In this climate PHPP generally delivers more unfavourable results for all windows, although absolute differences specifically for the most efficient windows get very small. Nevertheless altogether we see a very good match of results. The most probable result for the differences are different climate data sets used by PHPP (usually tested and corrected international climate data sets are used) and Task 7 where Meteonorm data are used. Please note that we focus on space heat only.

The reference comparison for the North and South climate can be found in the Annex (Figure 11 and Figure 12). Also for those orientations differences between both calculations are small. Only for the best windows (no. 6) we note that in PHPP performance does not significantly change from climate zone to climate zone. This might be due to a stricter consideration of the length of heating period which gets ever shorter from North to South, consequently squeezing the window more and more into the most unfavourable solar time of the year.

When classifying the 11 windows in ranks from 1 to 11 with 1 being the best option and 11 the worst the following figures appear for the central climate when comparing the PHPP and the Task 7 results.

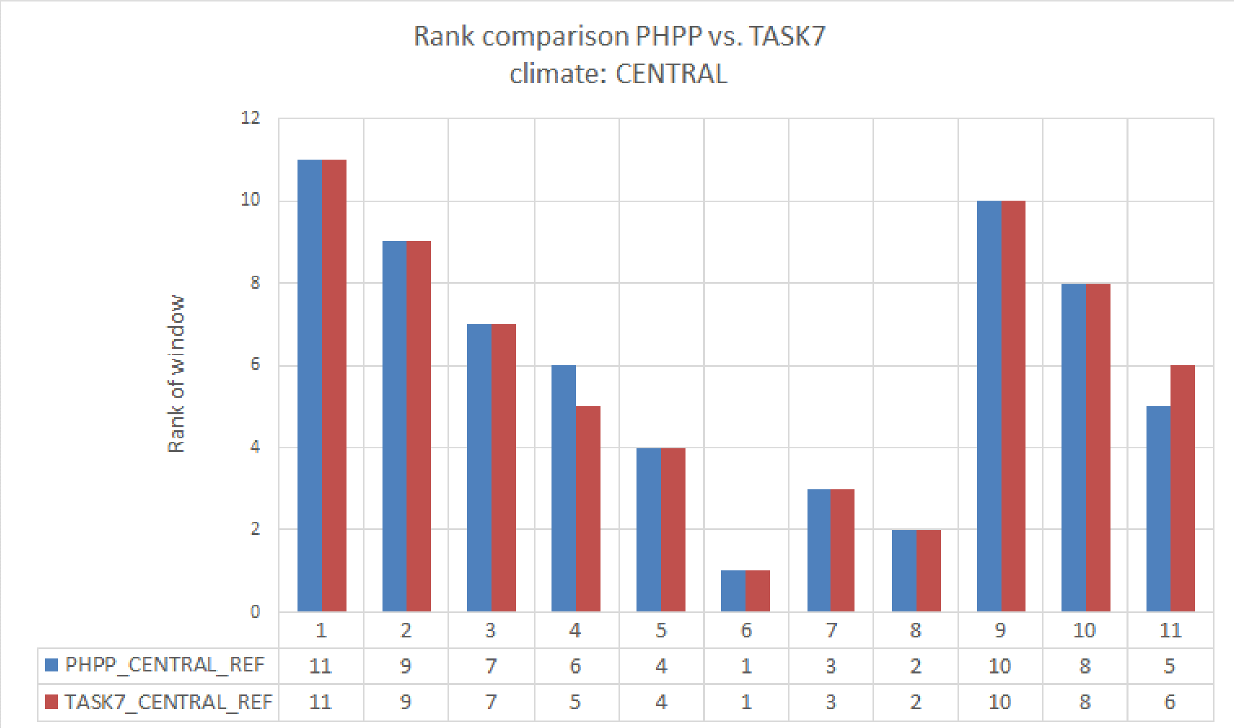



**Figure 7. Comparison of window performance PHPP vs. Task 7, Window rank, Central**

The figure shows that only window 4 (1.3/0.6) and 11 (0.8/0.35) change the rank when using the PHPP instead of the Task 7 results. This change originates from only a very small absolute difference (see figure with kWh/m² window above). As this minute difference most probably would not change the window's energy performance class it is not relevant.

Thus PHPP calculations for heating do not differ significantly from the Task 7 results and will be used to validate the Task 7 results for heating in the following chapters.

The following chapter evaluates three variations from the original set-up of the Task 7 calculations.

## 3.3 Variation of boundary conditions

In order to validate the Task 7 results the following three variations have been analysed that had not been considered thoroughly yet there. Figures show the results of this sensitivity analysis.

1. Shading
2. Row house
3. Climate

These variations are to be understood as sensitivity analyses in order to test the robustness of the Task 7 results. Although Task 7 report acknowledges the importance of the following factors, we didn't find an explanation why these sensitivity checks have not been performed.

**1. Variant: Shading (abbreviation: SHAD)**

We considered a shading coefficient which we deem to be realistic for an urban situation: Fc = 60% (i.e. 40% of solar radiation does not reach the window due to shading) resulting mainly from other buildings surrounding the model SFH.

**2. Variant: Row house (abbreviation: RH)**

In order to approximate a multi-family house we used the original model SFH and adjusted it to a row house by considering the East and West external walls to be adiabatic and having no windows. Based on a thorough analysis of the TABULA database[20] across EU MS, a lower window to floor area ratio of 15% (in comparison to 20% for detached houses) turned out to be realistic for row houses. This leads to higher window areas for the remaining two orientations (North/South) of 12.2 instead of 8.1 $m^2$ each.

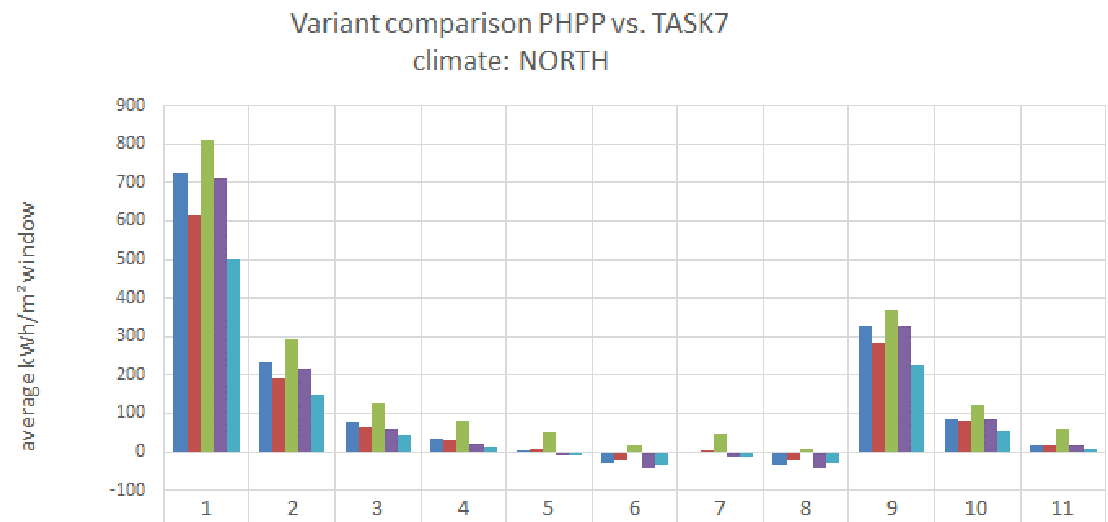
**3. Variant: Climate (abbreviation: CLIM)**

For the climate variation a climate was chosen that lies in between the climate zones Central and North concerning the heating degree days (HDD, 20°C, according to PHPP) and the horizontal irradiation (according to PHPP).

**Table 5. Climate data used (values taken from PHPP- Passive House Project Package)**

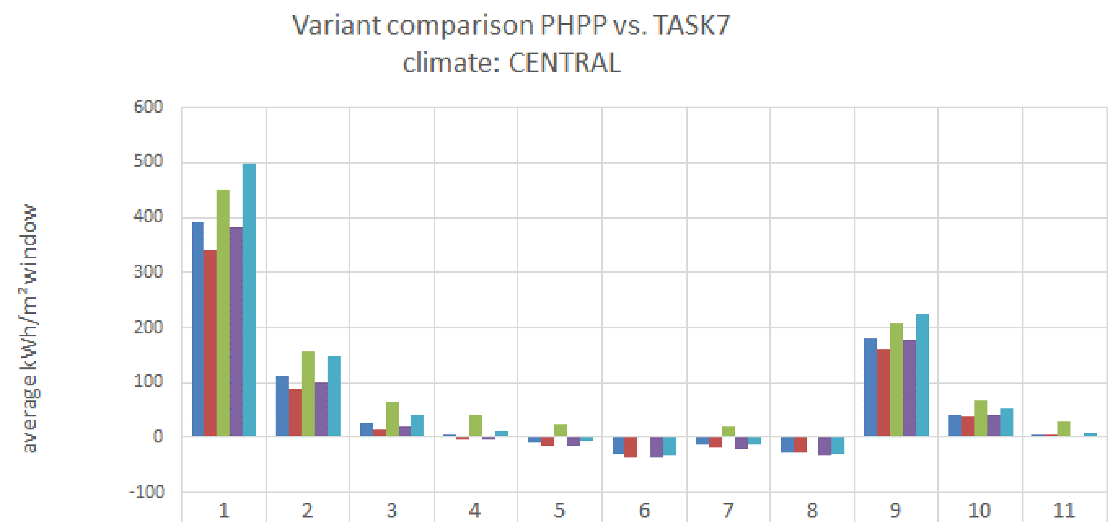
| PHPP climate | Heating Degree Days (HDD, base = 20°C) [Kd/a] | Horizontal irradiation [kWh/(m²a)] |
|---|---|---|
| NORTH Helsinki | 4,520 | 215 |
| CENTRAL Strasbourg | 2,910 | 335 |
| SOUTH Athens | 804 | 326 |
| CLIM Potsdam | 3,414 | 288 |

[20] http://webtool.building-typology.eu/webtool/tabula.html?



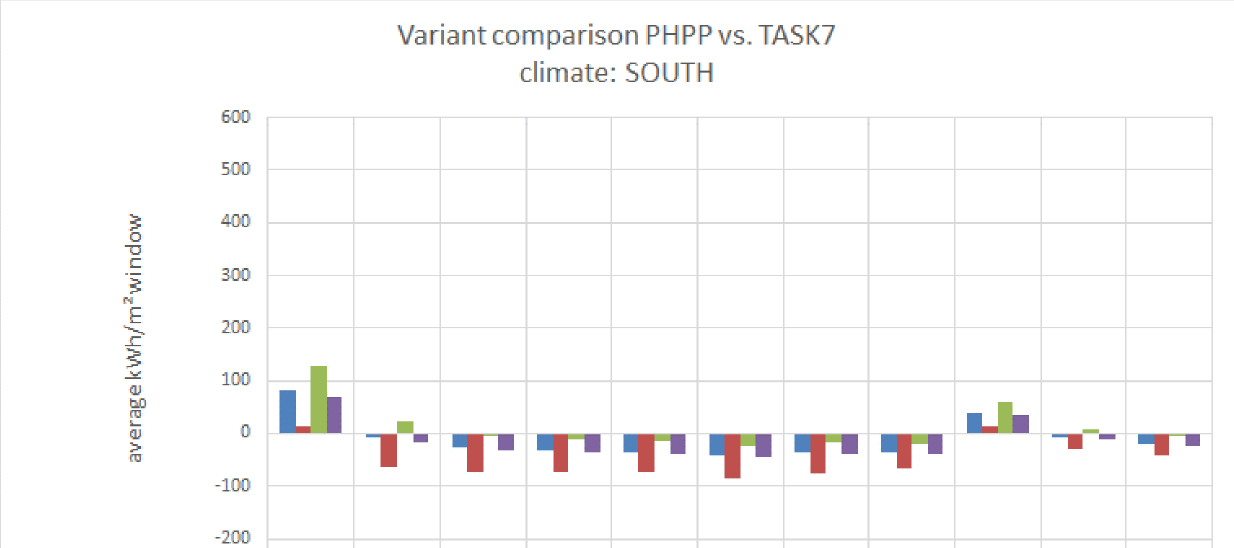

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_NORTH_REF | 725 | 232 | 75 | 33 | 3 | -30 | -2 | -33 | 326 | 85 | 19 |
| TASK7_NORTH_REF | 616 | 190 | 63 | 30 | 8 | -21 | 4 | -20 | 285 | 82 | 16 |
| PHPP_NORTH_SHAD | 807 | 294 | 127 | 82 | 50 | 16 | 46 | 10 | 369 | 125 | 58 |
| PHPP_NORTH_RH | 712 | 214 | 60 | 20 | -7 | -44 | -14 | -40 | 326 | 84 | 17 |
| PHPP_CLIM | 498 | 148 | 40 | 12 | -7 | -32 | -12 | -31 | 225 | 54 | 8 |

**Figure 8. Results of sensitivity analysis for climate North.**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_CENTRAL_REF | 392 | 112 | 28 | 6 | -9 | -30 | -13 | -28 | 180 | 42 | 5 |
| TASK7_CENTRAL_REF | 340 | 88 | 16 | -3 | -14 | -36 | -19 | -28 | 160 | 39 | 6 |
| PHPP_CENTRAL_SHAD | 452 | 158 | 65 | 40 | 23 | 3 | 20 | 1 | 208 | 68 | 30 |
| PHPP_CENTRAL_RH | 382 | 101 | 19 | -2 | -15 | -37 | -20 | -32 | 178 | 40 | 3 |
| PHPP_CLIM | 498 | 148 | 40 | 12 | -7 | -32 | -12 | -31 | 225 | 54 | 8 |

**Figure 9. Results of sensitivity analysis for climate Central.**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_SOUTH_REF | 83 | -8 | -28 | -32 | -35 | -42 | -37 | -37 | 39 | -9 | -21 |
| TASK7_SOUTH_REF | 14 | -64 | -74 | -74 | -72 | -85 | -77 | -67 | 13 | -29 | -41 |
| PHPP_SOUTH_SHAD | 128 | 24 | -4 | -10 | -14 | -22 | -16 | -19 | 60 | 9 | -5 |
| PHPP_SOUTH_RH | 69 | -16 | -33 | -36 | -37 | -45 | -40 | -38 | 35 | -11 | -22 |

**Figure 10. Results of sensitivity analysis for climate South.**

## 3.4 Interpretation of results

### Rank of windows

Obviously windows No. 1 and 9 are the worst performers in all climate regions in the heating season. In North and Central also window No. 2 clearly falls behind the others. These are the windows with highest U-values, thus the impact of U-values in colder climates gets very visible. Note the different scale in Figure 8, North.

### Absolute performance difference of windows

In order to get a better feeling for the real significance of energy performance differences between windows, keep in mind that except for the row houses the window to floor ratio is 20%. This means: a difference of 5 kWh/m$^2$a *window* area boils down to 20% of this value, i.e. 1 kWh/m$^2$a relative to the floor area. This exercise can easily be performed for each window/floor-ratio. The lower the window share the smaller the impact on the building energy performance. This is why especially older very efficient buildings (relative to energy need for space heating) sometimes feature quite small window areas, specifically in North orientation, as these windows have significant net energy losses.

As we think this aspect gets lost when only looking at window specific energy performance we created the following tables assuming that always all orientations get the same window:

**Table 6. Specific heating demand of reference SFH and share of windows**

| REFERENCE | | | SHADING | | |
|---|---|---|---|---|---|
| heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand | heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand |
| 341 | 145 | 43% | 361 | 161 | 45% |
| 241 | 46 | 19% | 257 | 59 | 23% |
| 210 | 15 | 7% | 224 | 25 | 11% |
| 202 | 7 | 3% | 215 | 16 | 8% |
| 197 | 1 | 0% | 209 | 10 | 5% |
| 189 | -6 | -3% | 202 | 3 | 2% |
| 195 | 0 | 0% | 208 | 9 | 4% |
| 191 | -7 | -3% | 202 | 2 | 1% |
| 265 | 65 | 25% | 274 | 74 | 27% |
| 216 | 17 | 8% | 225 | 25 | 11% |
| 203 | 4 | 2% | 212 | 12 | 5% |

| CENTRAL | | | | | |
|---|---|---|---|---|---|
| REFERENCE | | | SHADING | | |
| heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand | heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand |
| 178 | 78 | 44% | 191 | 90 | 47% |
| 121 | 22 | 19% | 132 | 32 | 24% |
| 104 | 6 | 5% | 113 | 13 | 11% |
| 100 | 1 | 1% | 108 | 8 | 7% |
| 97 | -2 | -2% | 105 | 5 | 4% |
| 93 | -6 | -6% | 101 | 1 | 1% |
| 96 | -3 | -3% | 104 | 4 | 4% |
| 94 | -6 | -6% | 101 | 0 | 0% |
| 137 | 36 | 26% | 143 | 42 | 29% |
| 109 | 8 | 8% | 115 | 14 | 12% |
| 101 | 1 | 1% | 107 | 6 | 6% |

| SOUTH | | | | | |
|---|---|---|---|---|---|
| REFERENCE | | | SHADING | | |
| heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand | heating demand kWh/m2a floor area | window N/E/S/W / 4 kWh/m2a floor area | Share heat loss windows from heating demand |
| 40 | 17 | 42% | 49 | 26 | 52% |
| 21 | -2 | -7% | 28 | 5 | 17% |
| 17 | -6 | -33% | 23 | -1 | -3% |
| 16 | -6 | -41% | 22 | -2 | -9% |
| 15 | -7 | -45% | 21 | -3 | -14% |
| 13 | -8 | -63% | 19 | -4 | -24% |
| 15 | -7 | -50% | 20 | -3 | -16% |
| 15 | -7 | -48% | 20 | -4 | -19% |
| 32 | 8 | 25% | 36 | 12 | 33% |
| 22 | -2 | -8% | 26 | 2 | 7% |
| 19 | -4 | -22% | 23 | -1 | -4% |

The three tables show all three climates. The first column shows the specific (i.e. per $m^2$ floor area), energy *need* of the whole building. The second column shows the specific (here as well per $m^2$ FLOOR area) energy need as an average of all windows. This is the balance of losses and savings of the window. Negative values show net gains. The third column the share of the window in the total energy balance of the building. Columns 4-6 show the same for an urban situation with shading.

Table 6 highlights several aspects:

- Assuming adiabatic windows (neither losses nor gains) the specific energy performance of the "rest" of the building is about 200 kWh/m²a in North, 100 kWh/m²a in Central and 23 kWh/m²a in South. Note that we always applied the same building envelope having an average U = 0.6 W/m²K.
- Remember that the energy performance of new built-residential nearly-zero energy buildings in terms of specific energy need (sum of heating & cooling) is assumed to be about < 25 kWh/m²a in North, < 15 kWh/m²a in central and 15-30 kWh/m²a in South (ECOFYS 2013, Executive Summary.). In this context both North and Central buildings are very bad. Also South buildings would need improvement considering that cooling will come on top.
- In this context absolute differences between windows need to be evaluated. We take the results of the PHPP calculations:
  - In North the range between non-G windows (1, 2, 3, 9, 10) is approximately 14 kWh/m²a floor area. This is roughly half of the NZEB "allowance" in North.
  - In Central the range between non-G windows (1, 2, 9, 10) is approximately 12 kWh/m²a. This is roughly the NZEB "allowance" in Central.
  - In South the range between non-G windows (1, 9, 10) is approximately 6 kWh/m²a floor area. Especially the performance of windows 2 is much worse in PHPP than in Task 7. This discrepancy needs further analysis.
  - => the numbers show a very high ambition level of the proposed energy classes. Also the intention of the EC is clear: regardless in which climate zone the consumer is: the intervals of heating energy classes are meant to have equal size. From an economic (cost-benefit) perspective this is understandable.
- Absolute differences between windows 1-11 get smaller from North, via Central to South. Due to the energy class logic shown before this results in more and more windows being put into the G class from South to North.

**Impact of shading from e.g. trees and surrounding buildings**

As to detailed kWh results and ranks please see Table 7 and Table 8 in the Annex.

- The higher the g-value the more influence shading has on the absolute window energy performance. While all windows lose part of what they can contribute as passive solar gains, these losses are stronger with higher g-value windows. This means that in the currently proposed label either a high g-value window may be rated better (e.g class C) than another window (e.g. class D) without shading by trees etc., but it may actually have the same performance level when taking into account the real situation with shading by trees etc. (of

course assuming these two windows would be installed at the same place).
The same goes for windows being in the same class; the higher g-value windows moves "quicker" towards worse ratings the stronger the shading by trees etc. is, so might easily lose a class against lower g-value windows. This may even lead to a change in windows ranking in real life.

- The shading impact just described is obviously stronger when looking at windows for South orientation than for looking at the average rating made up of all four orientations. Then more sun a window theoretically can get the higher the impact of the g-value for the rating and the higher the probability that windows may change ranking relative to each other.
- Concrete examples are windows 3 (1.7/0.65) and 11 (0.8/0.35). In the South location they would have a rating of D or F respectively. The D rated window is the much better alternative in an unshaded South orientation, slightly better in East and West and more significantly worse in North orientation. The South-orientation performance is responsible for the final better rating. When looking at the energy performance considering moderate urban shading, window 3 loses its advantage. Its disadvantage in North orientation is growing, now it's slightly worse in East and West orientation and a significant share of the advantage in South orientation has melted away. Eventually the label F window even has a minimal better overall performance in a shaded situation.
- Considering shading, windows may easily lose 3-4 classes in real life due to the very ambitious scale of the suggested label. Example: window 4 in Central climate, rated "E". According to PHPP calculation the window loses 34 kWh/m$^2$a of energy performance in a shaded situation, which is almost equivalent to the bandwidth of three energy label classes. The real performance moves far into the "G" area. In contrast windows 10 and 11 "only" lose about 25 kWh/m$^2$a according to PHPP calculation.

**Impact of orientation**

- One objective of the energy label is small scale renovation. This means exchange of windows, which in this case could happen just for selected orientations. The calculation results show, that specifically the ranking of windows in Southern orientation can differ significantly from the overall ranking and of course especially from the ranking in Northern direction. A very good example is window No. 11, which changes rank significantly depending on the orientation in the Central region, or window No. 8 in Southern region during heating season. .

**Impact of installing windows in row house instead of SFH**

- Having a typical "row type" building either row house or inner-city multi-family building may easily have the situation where only South- and North-bound windows exist. Looking at "RH_Rank" in Table 8 (Annex), please compare the columns N(orth) and S(outh) with the overall ranking given by Task 7. In Northern and Central climate windows 3 and 11 are good examples for change of place, whereas in Southern climate quite there even more movement can be observed.

**Dependency of energy performance from efficiency of heat/cold source**

- The possibility of a combined label is also included in the proposed delegated regulation. This means adding heating and cooling energy performance. We'd like to state that the window energy label illustrates a ranking while the fiche states absolute numbers in terms of energy *need*. A layman consumer most probably won't understand this is not equivalent to the delivered energy which determines the energy bill.
- As to adding up heating and cooling from an energy need point of view in theory is correct, but it gives unclear guidance as to which actual delivered energy and energy cost may be expected. In many cases heating is provided by a boiler system while cold is provided by an electric chiller (if at all in residential buildings). From this point of view the sum of heating and cooling need for the layman disguises the impact on the energy bill.

**Impact of installing windows "between" climate zones**

- Calculations for "Potsdam" which is between North and Central climate as expected shows some small differences in ranking to both climates but absolute differences which may easily span one or two classes' bandwidth.
- This is another illustration of the high sensitivity of window energy performance to the actual location of installation.

Obviously windows No. 1 and 9 are the worst performers in all climate regions. In North and Central also window No. 2 clearly falls behind the others. These are the windows with highest U-values, thus the impact of U-values in colder climates gets very visible.

**Finding 15**

- In our opinion the proposed *magnitude* of energy class *intervals* (without shutter) presented in Table 1 of the draft delegated regulation makes sense (regardless whether including the whole life-cycle or only the use phase), having in mind the long-term target of nearly-zero energy building and that differences in classification are to give an indication about potential savings. As classes have the same intervals in all climate regions this leads to the fact that more windows move towards class G, or in other words much more windows can be found in classes C and D in the South climate as their heating performance is very similar.
- In the current proposal there is no window rated better than C. We assume that few windows that can be found in the Passive House database of certified components might qualify for class B in Northern climate. We did nor analyse this so far. While it certainly is a big challenge to develop "A" rated windows according to the current proposal, we would not per se exclude this possibility for façade windows considering developments during the last two decades. Some U/g-value combinations qualifying for class "A" could be easily determined to see how far current BAT windows are from class A.

**Finding 16**

- Shading by trees and other (urban) surroundings is not included in the energy performance values underlying the energy label classes. This leads to ideal energy performance statements which systematically deviate from reality. Specifically with a view to the long-term target of a climate neutral building stock, this is an unrealistic assumption that will create significant differences from performance stated on the label to real-life performance in the *majority* of cases.
- Here the consumer might be misguided towards a sub-optimal window choice for his specific case, especially when it is about choosing the most suitable window for Southern or Northern orientation, where those two directions may have significantly different shading by trees etc.
- Therefore a solution should be found to show the significant impact shading may have on absolute and relative window performance.

**Finding 17**

- Performance by orientation is not visible on the label. Nevertheless, as the results show, window energy performance is quite significantly dependant on orientation. In order to achieve a low energy building stock, it will be more and more adequate to use different windows in different orientations of the same building. Here the consumer might be misguided towards a sub-optimal window choice for his specific case
- Therefore a solution should be found to show the significant impact orientation may have on absolute and relative window performance.

**Finding 18**

- Compared to other labels the proposed window energy label intends to present the "energy need", which is the balance of losses and gains through the windows. Between the window energy balance and the energy bill (= delivered (final) energy) is the heating system which has a certain efficiency. This is a significant difference compared to other "White Ware" labels or car labelling where the final energy is shown, i.e. the energy form the consumer actually needs to buy.
- Depending on the type of heating system and the efficiency of this system quite different numbers for real delivered energy (electricity, gas, heating oil ...) can occur compared to the energy need stated on a potential window energy label. We suppose that it will be very hard to clearly reveal this difference to other labels consumers are accustomed to.
- Therefore a solution would be preferable which gives an indication – at least on the fiche - about the energy performance in terms of actual delivered energy. Yet this would add another piece of information on top of performance by orientation etc. which practically makes it an even bigger challenge to fit all that information on an easy to grasp label.

**Finding 19**

- As the consumer probably tends to expect a clear indication about energy cost (related to *delivered energy* he/she has to purchase) from the information provided on the label, heating and cooling energy *needs. which thus are of very limited meaning for the final consumer,* rather should not be presented as one single number. This is because heating and cooling may easily be provided by different generators for heat and cold, running on different types of delivered energy. Furthermore, for the majority of residential consumers only heating or cooling performance will be relevant.

# 4 Conclusion and recommendations

In this brief study we have analysed several aspects of the proposed energy label for windows. We found that the underlying Task 7 report from the windows preparatory study is a massive piece of work where the authors have put in a lot of effort and competency.

Generally we very much appreciate and support the will to find ways to fully exploit the energy saving potential in windows. As we have pointed out in the past, overarching savings targets for the building sector like the 88%–91% in the "EU Roadmap for Moving to a Low-Carbon Economy" are *extremely* ambitious.

Yet from the information provided in Task 7 report and estimates we performed ourselves we are not convinced that the current proposal will significantly boost energy performance of windows and thus primary energy savings compared to a realistic Business-As-Usual scenario or compared to the 91% BAU residential savings for 2010 to 2050 in the Task 7 report. Summarizing our detailed findings we mainly see the following reasons. Please note we focused on *heating energy in residential buildings*:

- We find "heating energy" for windows values in the BAU for 2010 too high, mainly because of over-estimated window areas in heated buildings and under-estimated heating system efficiency.
- Considering the results of MS's cost-optimality calculations, window requirements already in place in MS, the obligation to introduce nearly zero energy buildings by 2019/2021 for new buildings, the requirement of the Energy Efficiency Directive's requirement to set up renovation roadmaps and the important role window energy performance has in the NZEB and low-energy building concepts we find the assumptions for window energy performance (heating) in 2020 in the BAU scenario too pessimistic.
- Furthermore, as an energy label probably would not impact the market before 2018 the savings shown in the "energy label scenarios" till 2020 compared to BAU seem to be too optimistic.
- Consequently we find the all over heating energy savings estimates in the Task 7 report that can be achieved by an energy label too optimistic.
- Savings by more efficient heating systems and more efficient windows carefully need to be separated. It is unclear to what extent this has happened in the Task 7 report which is underlying the draft delegated regulation and Explanatory Memorandum.
- Moreover it is not fully transparent in the Task 7 report to what extent actual energy performance rather than theoretical energy performance is the basis for the calculation of window energy saving potentials. From our calculations we derive that theoretical savings have been assumed rather than real life savings. Real life savings should be calculated based on typical window locations within urban areas (trees, surrounding buildings). Ideally also potential rebound effects (higher indoor air temperature after window exchange) should be considered.

- Energy performance of windows is much more sensitive to its allocation than is the case e.g. for white goods. While it is very good that the label makes a difference between different climates, we'd like to stress that window orientation, real-life shading by trees, other building parts or surrounding buildings, as well as the efficiency of the heating system have an enormous impact on the actual savings that can be achieved by a window replacement. This multitude of crucial performance parameters – which is also required to be considered in Annex I EPBD - is not yet reflected in the proposed energy label. Actually the solution found in Task 7 report with A, B, C values already produces surprisingly not to say amazingly stable results as to the *ranking* of windows. Yet it doesn't perfectly work when it is about differentiating between very efficient windows, which have rather small differences in energy performance. Still these small differences get relevant in low energy buildings which must be the standard in order to achieve EU climate targets. Differences in ranking may also occur in regions where the customer can't be sure which climate zone he/she belongs to. Therefore the current proposal won't guide a significant share of consumers to the best possible product for their specific situation.
- We acknowledge that the authors of the Task 7 report have put an enormous effort in it. Yet we could not find some pieces of information about crucial assumptions; this hampers a proper validation and discussion of some numbers in the report (like savings). As the success of a potential energy label needs to be measured against the *actual* energy savings it may achieve, utmost transparency of the assumptions and discussion with relevant stakeholders should be achieved. To our impression this was not fully the case in between the point in time where the final consolidated version of the Task 7 report was available and publication of the draft delegated regulation.
- There are no convincing arguments neither in the Task 7 report nor in the Explanatory Memorandum why an Energy Label is the preferred way to mobilise additional savings on top of the push exerted by EPBD recast requirements, e.g. compared to *fully* using the possibilities given by the Construction Products Regulation and the EC marking.
- We see a significant risk that a window energy label with the current sole focus on energy-in-use from the perspective of *total life-cycle-savings* – the latter being the decisive one for reaching EU energy efficiency goals - will be much less successful. Best available technology windows today have reached a point where additional savings in use are compensated to a large extent by additional primary energy inputs for other life cycle phases. This is on top of our finding that potential heating energy-in-use savings for windows appears to be overestimated. Thus net savings achieved within EU28 considering *all* life-cycle phases are much smaller than stated in the preparatory study and the Explanatory Memorandum for the use phase only. It is recommended to do another calculation on this real total savings impact windows can have.
- Furthermore a label will trigger an "energy-in-use" race between manufacturers, although, as mentioned, the decisive objective is to minimise life-cycle energy use. From the LCA data given in the preparatory study, up to 50% of the energy-savings-in-use advantage of a window compared to another window may be compensated by additional inputs in other life cycle phases, mainly production. As energy-in-use in the preparatory study to our understanding also in the LCA is calculated under ideal circumstances, real

life differences between windows may even be smaller than the additional primary energy input needed e.g. in production. Please note that once a window has been produced, the additional primary energy input compared to another window is fixed, whereas the future primary energy saving very much depends on assumptions about where the window is used and the efficiency of energy supply systems. It is safe to assume that the energy efficiency of supply will significantly improve during the lifetime of a window. A window installed today may easily last till 2050, so the delivered energy due to the same window will steadily decrease over time.

- In contrast to the statement in the Explanatory Memorandum we think an energy label for windows *will* cause a significant additional burden to window manufacturers, especially to SMEs. Not all information needed for the calculation of the window energy performance according to the rules set out in the delegated regulation is readily available through CE marking in each MS and thus would need additional testing. Above, detailed calculations usually deliver more favourable U-values for windows than tabulated values – therefore manufacturers will feel to be forced to go for more expensive detailed calculations, to avoid their window look worse on the energy label just because of different calculation methods for the U-value as mandated characteristic – although objectively it may have the same performance as a competitor's window.
- As to the proposed layout of the energy label, we already mentioned that we don't think it already includes all parameters which are decisive for the selection of the best possible window (from an energy perspective) for a specific situation. Yet already the current version includes quite a lot of information. Therefore it must be ensured that the consumer really understands the label in a way that will not misguide him/her. We recommend to check this important question by means of a small survey for different label designs. It might turn out, that there is no design that achieves sufficient comprehension.
- Taking the previous point further the window label shows the theoretical "energy *needs*", i.e. the balance of losses and gains of the window itself, rather than "delivered energy" which the customer has to pay for and which may differ significantly from "energy needs" due to distribution losses of pipes and generation losses of e.g. a boiler. This is different from other energy labels and probably hard to convey to the customer.

In a nutshell we recommend to re-assess some of the assumptions and findings of the Task 7 study, specifically as to BAU assumptions and total primary energy that may be saved. We would welcome if some of the assumptions which can't be found in Task 7 report would be published in order to allow follow-up discussion and validation by stakeholders who in the end will be affected by such label.

The 2050 building stock on average needs to consist of NZEB to meet the very ambitious climate targets. NZEBs only can be achieved by a holistic building design, where windows play a prominent role. In this context the current proposal for an energy label seems to be oversimplified and may mislead a significant quantity of consumers, incl. building professionals. We very much appreciate the EC's will to find the best way to fully exploit windows' savings potential. Therefore we recommend to re-assess the proposed energy label as a whole relative to its necessity, feasibility and added value.

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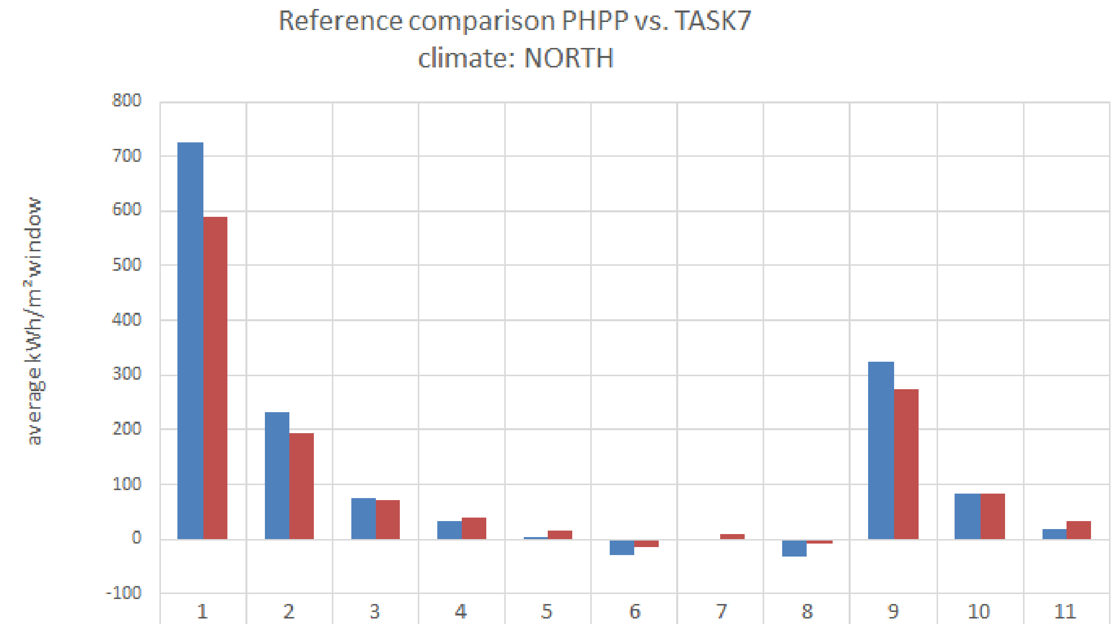
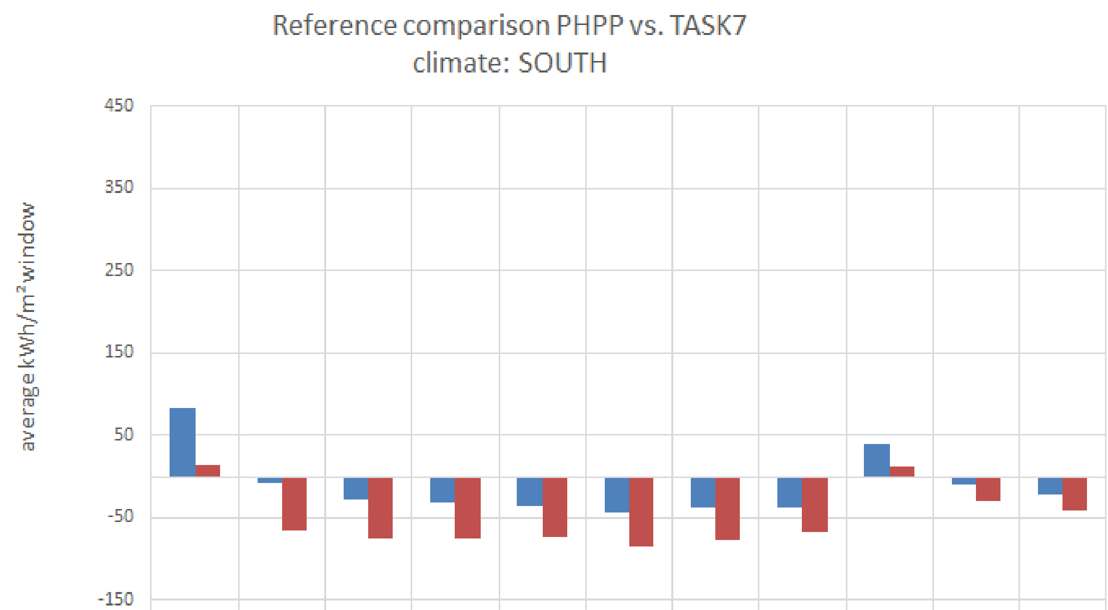
# 6 Annex



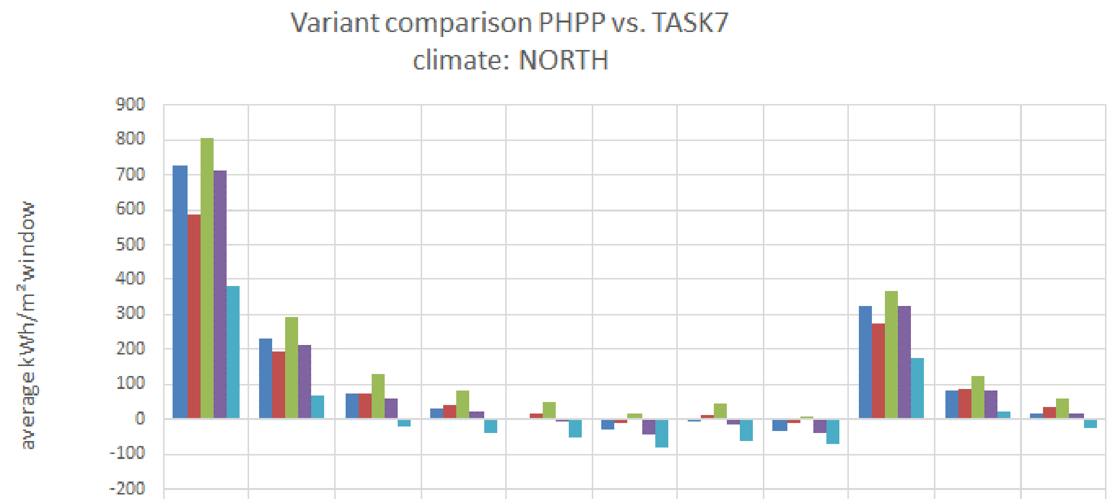

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_NORTH_REF | 725 | 232 | 75 | 33 | 3 | -30 | -2 | -33 | 326 | 85 | 19 |
| TASK7_NORTH_REF | 588 | 193 | 71 | 39 | 17 | -13 | 11 | -9 | 273 | 85 | 34 |

**Figure 11. Comparison of window performance PHPP vs. Task 7, North, Reference comparison, kWh/m²window**



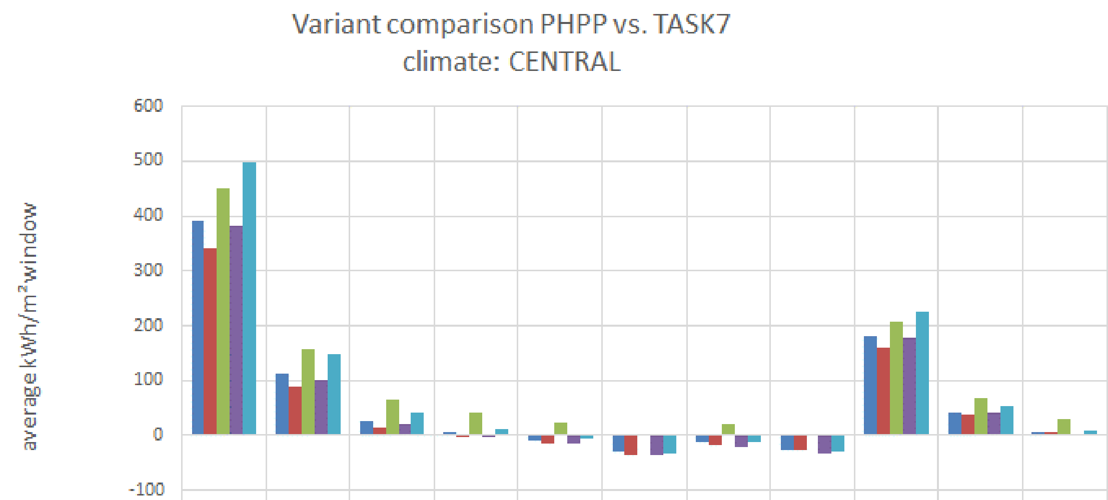

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_SOUTH_REF | 83 | -8 | -28 | -32 | -35 | -42 | -37 | -37 | 39 | -9 | -21 |
| TASK7_SOUTH_REF | 14 | -64 | -74 | -74 | -72 | -85 | -77 | -67 | 13 | -29 | -41 |

**Figure 12. Comparison of window performance PHPP vs. Task 7, South, Reference comparison, kWh/m²window**



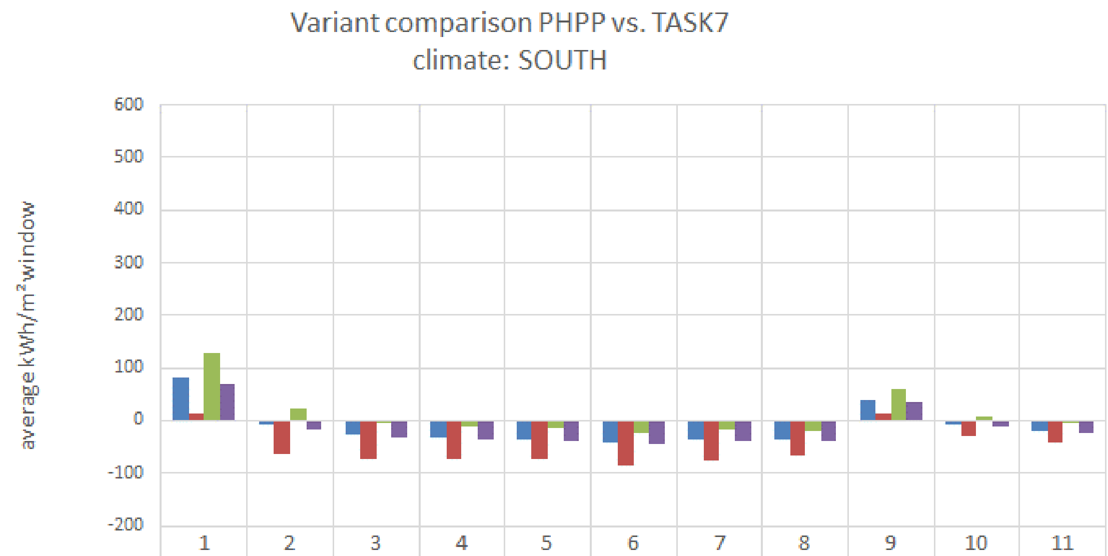

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_NORTH_REF | 725 | 232 | 75 | 33 | 3 | -30 | -2 | -33 | 326 | 85 | 19 |
| TASK7_NORTH_REF | 588 | 193 | 71 | 39 | 17 | -13 | 11 | -9 | 273 | 85 | 34 |
| PHPP_NORTH_SHAD | 807 | 294 | 127 | 82 | 50 | 16 | 46 | 10 | 369 | 125 | 58 |
| PHPP_NORTH_RH | 712 | 214 | 60 | 20 | -7 | -44 | -14 | -40 | 326 | 84 | 17 |
| PHPP_CLIM | 382 | 70 | -18 | -40 | -54 | -80 | -60 | -69 | 177 | 20 | -23 |

**Figure 13. Comparison of window performance in different contexts, North, kWh/m²window**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_CENTRAL_REF | 392 | 112 | 28 | 6 | -9 | -30 | -13 | -28 | 180 | 42 | 5 |
| TASK7_CENTRAL_REF | 340 | 88 | 16 | -3 | -14 | -36 | -19 | -28 | 160 | 39 | 6 |
| PHPP_CENTRAL_SHAD | 452 | 158 | 65 | 40 | 23 | 3 | 20 | 1 | 208 | 68 | 30 |
| PHPP_CENTRAL_RH | 382 | 101 | 19 | -2 | -15 | -37 | -20 | -32 | 178 | 40 | 3 |
| PHPP_CLIM | 498 | 148 | 40 | 12 | -7 | -32 | -12 | -31 | 225 | 54 | 8 |

**Figure 14. Comparison of window performance in different contexts, Central, kWh/m²window**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PHPP_SOUTH_REF | 83 | -8 | -28 | -32 | -35 | -42 | -37 | -37 | 39 | -9 | -21 |
| TASK7_SOUTH_REF | 14 | -64 | -74 | -74 | -72 | -85 | -77 | -67 | 13 | -29 | -41 |
| PHPP_SOUTH_SHAD | 128 | 24 | -4 | -10 | -14 | -22 | -16 | -19 | 60 | 9 | -5 |
| PHPP_SOUTH_RH | 69 | -16 | -33 | -36 | -37 | -45 | -40 | -38 | 35 | -11 | -22 |

**Figure 15. Comparison of window performance in different contexts, South, kWh/m²window**

**Table 7. Overview of Energy Performance calculations**

NORTH

| | REFERENCE | | | | | SHADING | | | | | ROW HOUSE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 |
| 1 | 862 | 721 | 596 | 721 | **725** | 901 | 802 | 725 | 802 | **807** | 857 | 0 | 568 | 0 | **712** |
| 2 | 351 | 229 | 117 | 229 | **232** | 378 | 290 | 220 | 290 | **294** | 344 | 0 | 84 | 0 | **214** |
| 3 | 177 | 72 | -22 | 72 | **75** | 198 | 123 | 65 | 123 | **127** | 171 | 0 | -50 | 0 | **60** |
| 4 | 128 | 30 | -57 | 30 | **33** | 148 | 78 | 24 | 78 | **82** | 123 | 0 | -82 | 0 | **20** |
| 5 | 93 | 0 | -80 | 0 | **3** | 111 | 47 | -3 | 46 | **50** | 87 | 0 | -102 | 0 | **-7** |
| 6 | 64 | -32 | -119 | -32 | **-30** | 81 | 13 | -41 | 13 | **16** | 58 | 0 | -146 | 0 | **-44** |
| 7 | 91 | -4 | -89 | -4 | **-2** | 109 | 42 | -10 | 42 | **46** | 85 | 0 | -113 | 0 | **-14** |
| 8 | 46 | -36 | -106 | -36 | **-33** | 63 | 7 | -36 | 7 | **10** | 42 | 0 | -122 | 0 | **-40** |
| 9 | 391 | 322 | 269 | 322 | **326** | 410 | 366 | 334 | 366 | **369** | 390 | 0 | 263 | 0 | **326** |
| 10 | 149 | 81 | 28 | 81 | **85** | 165 | 122 | 90 | 122 | **125** | 147 | 0 | 21 | 0 | **84** |
| 11 | 82 | 15 | -37 | 15 | **19** | 98 | 55 | 23 | 55 | **58** | 80 | 0 | -45 | 0 | **17** |
| max-min | 131 | 117 | 147 | 117 | 118 | 135 | 117 | 131 | 117 | 117 | 129 | 0 | 167 | 0 | 128 |

CENTRAL

| | REFERENCE | | | | | SHADING | | | | | ROW HOUSE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 |
| 1 | 478 | 398 | 299 | 395 | **392** | 508 | 453 | 393 | 452 | **452** | 475 | 0 | 290 | 0 | **382** |
| 2 | 185 | 118 | 30 | 115 | **112** | 208 | 160 | 106 | 159 | **158** | 183 | 0 | 20 | 0 | **101** |
| 3 | 89 | 32 | -41 | 30 | **28** | 107 | 67 | 21 | 66 | **65** | 88 | 0 | -49 | 0 | **19** |
| 4 | 63 | 10 | -58 | 8 | **6** | 79 | 42 | 0 | 41 | **40** | 62 | 0 | -65 | 0 | **-2** |
| 5 | 44 | -6 | -68 | -8 | **-9** | 59 | 24 | -15 | 23 | **23** | 43 | 0 | -74 | 0 | **-15** |
| 6 | 27 | -25 | -93 | -27 | **-30** | 41 | 4 | -37 | 3 | **3** | 25 | 0 | -100 | 0 | **-37** |
| 7 | 42 | -9 | -75 | -11 | **-13** | 57 | 21 | -19 | 20 | **20** | 41 | 0 | -81 | 0 | **-20** |
| 8 | 19 | -25 | -79 | -26 | **-28** | 32 | 2 | -31 | 1 | **1** | 19 | 0 | -82 | 0 | **-32** |
| 9 | 219 | 181 | 139 | 180 | **180** | 232 | 208 | 183 | 207 | **208** | 218 | 0 | 138 | 0 | **178** |
| 10 | 80 | 43 | 2 | 42 | **42** | 92 | 68 | 43 | 68 | **68** | 79 | 0 | 1 | 0 | **40** |
| 11 | 42 | 6 | -35 | 5 | **5** | 53 | 30 | 5 | 29 | **30** | 42 | 0 | -36 | 0 | **3** |
| max-min | 70 | 68 | 95 | 69 | 71 | 75 | 66 | 81 | 67 | 67 | 69 | 0 | 101 | 0 | 78 |

SOUTH

| | REFERENCE | | | | | SHADING | | | | | ROW HOUSE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 |
| 1 | 144 | 93 | 5 | 92 | **83** | 170 | 133 | 76 | 133 | **128** | 135 | 0 | 4 | 0 | **69** |
| 2 | 41 | 1 | -72 | 1 | **-8** | 58 | 29 | -20 | 28 | **24** | 38 | 0 | -70 | 0 | **-16** |
| 3 | 12 | -21 | -81 | -21 | **-28** | 25 | 0 | -39 | 0 | **-4** | 12 | 0 | -77 | 0 | **-33** |
| 4 | 5 | -26 | -81 | -26 | **-32** | 16 | -7 | -43 | -7 | **-10** | 5 | 0 | -77 | 0 | **-36** |
| 5 | 0 | -29 | -80 | -29 | **-35** | 10 | -11 | -44 | -11 | **-14** | 1 | 0 | -75 | 0 | **-37** |
| 6 | -6 | -36 | -90 | -36 | **-42** | 3 | -19 | -54 | -19 | **-22** | -5 | 0 | -85 | 0 | **-45** |
| 7 | -1 | -31 | -84 | -31 | **-37** | 9 | -13 | -48 | -13 | **-16** | 0 | 0 | -79 | 0 | **-40** |
| 8 | -7 | -32 | -76 | -32 | **-37** | 2 | -16 | -45 | -16 | **-19** | -5 | 0 | -71 | 0 | **-38** |
| 9 | 67 | 43 | 5 | 42 | **39** | 78 | 62 | 39 | 62 | **60** | 63 | 0 | 7 | 0 | **35** |
| 10 | 16 | -6 | -41 | -6 | **-9** | 25 | 11 | -12 | 11 | **9** | 16 | 0 | -37 | 0 | **-11** |
| 11 | 4 | -18 | -53 | -18 | **-21** | 12 | -3 | -25 | -3 | **-5** | 4 | 0 | -48 | 0 | **-22** |
| max-min | 23 | 31 | 49 | 30 | 33 | 24 | 29 | 43 | 29 | 31 | 21 | 0 | 48 | 0 | 35 |

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| | REFERENCE | | | | | SHADING | | | | | ROW HOUSE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 | N=0 | E=0 | S=0 | W=0 | N/E/S/W / 4 |
| 1 | 493 | 377 | 280 | 379 | **382** | 544 | 469 | 410 | 471 | **473** | 488 | 0 | 269 | 0 | **378** |
| 2 | 167 | 66 | -22 | 67 | **70** | 207 | 139 | 86 | 141 | **144** | 163 | 0 | -36 | 0 | **63** |
| 3 | 64 | -22 | -95 | -20 | **-18** | 97 | 40 | -5 | 41 | **43** | 61 | 0 | -105 | 0 | **-22** |
| 4 | 37 | -44 | -112 | -42 | **-40** | 67 | 14 | -27 | 15 | **17** | 34 | 0 | -120 | 0 | **-43** |
| 5 | 17 | -58 | -120 | -56 | **-54** | 46 | -3 | -41 | -2 | **0** | 15 | 0 | -127 | 0 | **-56** |
| 6 | -4 | -83 | -151 | -82 | **-80** | 24 | -29 | -70 | -27 | **-25** | -7 | 0 | -161 | 0 | **-84** |
| 7 | 14 | -64 | -129 | -62 | **-60** | 43 | -8 | -48 | -7 | **-5** | 11 | 0 | -138 | 0 | **-63** |
| 8 | -7 | -73 | -126 | -71 | **-69** | 18 | -24 | -56 | -22 | **-21** | -9 | 0 | -131 | 0 | **-70** |
| 9 | 226 | 174 | 134 | 175 | **177** | 249 | 217 | 193 | 218 | **220** | 225 | 0 | 132 | 0 | **179** |
| 10 | 68 | 17 | -23 | 18 | **20** | 91 | 59 | 35 | 60 | **61** | 68 | 0 | -24 | 0 | **22** |
| 11 | 25 | -26 | -66 | -25 | **-23** | 47 | 16 | -8 | 16 | **18** | 25 | 0 | -67 | 0 | **-21** |
| | 76 | 100 | 128 | 100 | 100 | 79 | 88 | 105 | 87 | 87 | 77 | 0 | 136 | 0 | 106 |

**Table 8. Overview of energy performance ranks**

**NORTH**

| | ORIG | RANK | | | | SHAD | RANK | | | | RH | RANK | | | | Task 7 ranks | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | North | Cent | South |
| 1 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | | 11 | | 11 | 11 | 11 | 11 |
| 2 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | | 9 | | 9 | 9 | 9 | 7 |
| 3 | 8 | 7 | 7 | 7 | 7 | 8 | 8 | 7 | 8 | 8 | 8 | | 6 | | 7 | 7 | 7 | 3 |
| 4 | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | | 5 | | 6 | 6 | 5 | 3 |
| 5 | 5 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | | 4 | | 4 | 4 | 4 | 5 |
| 6 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | | 1 | | 1 | 1 | 1 | 1 |
| 7 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 4 | | 3 | | 3 | 3 | 3 | 2 |
| 8 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | | 2 | | 2 | 2 | 2 | 6 |
| 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | 10 | | 10 | 10 | 10 | 10 |
| 10 | 7 | 8 | 8 | 8 | 8 | 7 | 7 | 8 | 7 | 7 | 7 | | 8 | | 8 | 8 | 8 | 9 |
| 11 | 3 | 5 | 6 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 3 | | 7 | | 5 | 5 | 6 | 8 |

**CENTRAL**

| | ORIG | RANK | | | | SHAD | RANK | | | | RH | RANK | | | | Task 7 ranks | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | E | S | W | PHPP_CENTRAL_REF | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | North | Cent | South |
| 1 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | | 11 | | 11 | 11 | 11 | 11 |
| 2 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | | 9 | | 9 | 9 | 9 | 7 |
| 3 | 8 | 7 | 6 | 7 | 7 | 8 | 7 | 7 | 7 | 7 | 8 | | 6 | | 7 | 7 | 7 | 3 |
| 4 | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 5 | 6 | 6 | 6 | | 5 | | 5 | 6 | 5 | 3 |
| 5 | 5 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | | 4 | | 4 | 4 | 4 | 5 |
| 6 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | | 1 | | 1 | 1 | 1 | 1 |
| 7 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | | 3 | | 3 | 3 | 3 | 2 |
| 8 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | | 2 | | 2 | 2 | 2 | 6 |
| 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | 10 | | 10 | 10 | 10 | 10 |
| 10 | 7 | 8 | 8 | 8 | 8 | 7 | 8 | 8 | 8 | 8 | 7 | | 8 | | 8 | 8 | 8 | 9 |
| 11 | 3 | 5 | 7 | 5 | 5 | 3 | 5 | 6 | 5 | 5 | 4 | | 7 | | 6 | 5 | 6 | 8 |
| | | | | | | #N/A | | | | | | | | | | | | |

**SOUTH**

| | ORIG | RANK | | | | SHAD | RANK | | | | RH | RANK | | | | Task 7 ranks | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | North | Cent | South |
| 1 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | | 10 | | 11 | 11 | 11 | 11 |
| 2 | 9 | 9 | 7 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | | 7 | | 8 | 9 | 9 | 7 |
| 3 | 7 | 6 | 4 | 6 | 6 | 7 | 7 | 6 | 7 | 7 | 7 | | 4 | | 6 | 7 | 7 | 3 |
| 4 | 6 | 5 | 3 | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 6 | | 3 | | 5 | 6 | 5 | 3 |
| 5 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | 5 | | 4 | 4 | 4 | 5 |
| 6 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | | 1 | | 1 | 1 | 1 | 1 |
| 7 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | | 2 | | 2 | 3 | 3 | 2 |
| 8 | 1 | 2 | 6 | 2 | 3 | 1 | 2 | 3 | 2 | 2 | 1 | | 6 | | 3 | 2 | 2 | 6 |
| 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | 11 | | 10 | 10 | 10 | 10 |
| 10 | 8 | 8 | 9 | 8 | 8 | 8 | 8 | 9 | 8 | 8 | 8 | | 9 | | 9 | 8 | 8 | 9 |
| 11 | 5 | 7 | 8 | 7 | 7 | 5 | 6 | 7 | 6 | 6 | 5 | | 8 | | 7 | 5 | 6 | 8 |

**POTSDAM**

| | ORIG | RANK | | | | SHAD | RANK | | | | RH | RANK | | | | Task 7 ranks | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | N | E | S | W | N/E/S/W / 4 | North | Cent | South |
| 1 | 11 | 11 | 11 | 11 | **11** | 11 | 11 | 11 | 11 | **11** | 11 | | 11 | | 11 | 11 | 11 | 11 |
| 2 | 9 | 9 | 9 | 9 | **9** | 9 | 9 | 9 | 9 | **9** | 9 | | 8 | | 9 | 9 | 9 | 7 |
| 3 | 7 | 7 | 6 | 7 | **7** | 8 | 7 | 7 | 7 | **7** | 7 | | 6 | | 6 | 7 | 7 | 3 |
| 4 | 6 | 5 | 5 | 5 | **5** | 6 | 5 | 5 | 5 | **5** | 6 | | 5 | | 5 | 6 | 5 | 3 |
| 5 | 4 | 4 | 4 | 4 | **4** | 4 | 4 | 4 | 4 | **4** | 4 | | 4 | | 4 | 4 | 4 | 5 |
| 6 | 2 | 1 | 1 | 1 | **1** | 2 | 1 | 1 | 1 | **1** | 2 | | 1 | | 1 | 1 | 1 | 1 |
| 7 | 3 | 3 | 2 | 3 | **3** | 3 | 3 | 3 | 3 | **3** | 3 | | 2 | | 3 | 3 | 3 | 2 |
| 8 | 1 | 2 | 3 | 2 | **2** | 1 | 2 | 2 | 2 | **2** | 1 | | 3 | | 2 | 2 | 2 | 6 |
| 9 | 10 | 10 | 10 | 10 | **10** | 10 | 10 | 10 | 10 | **10** | 10 | | 10 | | 10 | 10 | 10 | 10 |
| 10 | 8 | 8 | 8 | 8 | **8** | 7 | 8 | 8 | 8 | **8** | 8 | | 9 | | 8 | 8 | 8 | 9 |
| 11 | 5 | 6 | 7 | 6 | **6** | 5 | 6 | 6 | 6 | **6** | 5 | | 7 | | 7 | 5 | 6 | 8 |

ECOFYS

sustainable energy for everyone

ECOFYS Germany GmbH

Albrechtstraße 10 c
10117 Berlin

T: +49 (0) 30 29773579-0
F: +49 (0) 30 29773579-99

E: info@ecofys.com
I: www.ecofys.com