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Final report

LOT 32 / Ecodesign of Window Products
TASK 6 – Design Options

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SUMMARY

This report presents the outcomes of the TASK 6 analysis of the "ENER Lot 32" Ecodesign Preparatory study, performed by VHK and ift Rosenheim, in collaboration with VITO.

Chapter 1 and 2 give a brief introduction to the study background (Chapter 1 Preface) and overall methodology (Chapter 2 Introduction).

Chapter 3 presents the design options for improving the environmental performance of windows. These are roughly the same technologies as addressed under TASK 4.

Chapter 4 gives an overview of the impacts of design options. The main differences are linked to the heating and cooling performances. The inputs for establishing the heating and cooling performances (ABC and XYZ values) are based on the information presented in TASKS 3, 5 and TASK 7.

Chapter 5 gives an overview of the costs of design options (base cases), drawing upon information from TASK 2.

Chapter 6 gives the results of the analysis of the life cycle costs of the options (base cases), which allows identification of the least life cycle cost (LLCC) or cost optimum option and the best-available technology (BAT) option (without consideration of cost optimum). The BAT and the LLCC are not the same window type for each climate condition.

Furthermore TASK 6 presents the outcomes of several sensitivity analyses, performed for window life, purchase costs, shutter[1] costs, heating efficiency and cooling costs / efficiency.

Chapter 7 gives an overview of technologies and development applicable to the long-term and the system (building) in which the window functions.

[1] The term shutters is to be understood comprising all kinds of solar shading devices, including blinds (if used externally).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS & ACRONYMS

AP	Acidification Potential
BAT	Best Available Technology
BNAT	Best Not yet Available Technology
BOM	Bill of Materials
CA	Concerted Action
C&D	Construction and demolition waste
CENELEC	European Committee for Electro technical Standardization
CEN	European Committee for Normalisation
CPD	Construction Products Directive
CPR	Construction Products Regulation
EN	European Norm
EOL	End Of Life
EOTA	European Organisation for Technical Assessment
EP	Eutrophication Potential
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
EPS	Expanded Polystyrene
ETAG	European Technical Approval Guidelines
EU	European Union
EuP	Energy using Products
ErP	Energy related Products
FDES	Fiches de Déclaration Environnementale et Sanitaire
GWP	Global Warming Potential
HM	Heavy Metals
IAQ	Indoor Air Quality
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LLCC	Least Life Cycle Cost
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy using Products
MEPS	Minimum Energy Performance Standard
MS	Member State
NEEAP	National Energy Efficiency Action Plan
NMVOC	Non Methane Volatile Organic Compound

NZEB	Nearly Zero Energy Building
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEF	Organisational Environmental Footprint
PEF	Product Environmental Footprint
PEFCRs	Product Environmental Footprint Category Rules
PM	Particulate Matter
POP	Persistent Organic Pollutants
POCP	Photochemical Oxidant Creation Potential
PRODCOM	PRODuction COMmunautaire
RES	Renewable Energy Sources
RoHS	Restriction of the use of certain Hazardous Substances
CI/SfB	Construction Index/Samarbetskommitten for Byggnadsfrago
SME	Small and Medium sized Enterprise
TC	Technical Committee
TR	Technical Report
VITO	Flemish Institute for Technological Research
VOC	Volatile Organic Compounds

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CHAPTER 1 PREFACE

This report has been prepared by ift Rosenheim and Van Holsteijn en Kemna BV (VHK) in collaboration with the Flemish Institute for Technological Research (VITO), under the Multiple Framework Contract related to preparatory studies and related technical assistance on specific product groups (ENER/C3/2012-418-Lot 1), and in response to the Terms of Reference included in the Contract for the "Ecodesign study with regard to Windows".

The subject of this report falls under the general context of sustainable industrial policy which aims to foster the development of products with less environmental impacts.

Directive 2009/125/EC ("Ecodesign Directive") is the cornerstone of this approach as it establishes a framework for the setting of Ecodesign requirements for energy-related products (ErPs) with the aim of ensuring the free movement of these products within the internal market. Directive 2009/125/EC targets ErPs as these account for a large portion of the consumption of energy and natural resources, and a number of other environmental impacts, in the Community, in particular during their use phase.

Directive 2010/30/EC on the energy labelling of ErPs is complementary to the Ecodesign Directive as it requires (a.o.) information on the impact by these products on the use of essential resources to be provided to consumers at the point of sale.

Any measure prepared under these directives must be preceded by a study or assessment ('preparatory study') that sets out to collect evidence and stakeholder input, explore policy options and describe the recommended policy mix (ecodesign and/or labelling and/or self-regulation measures).

The product groups considered as priorities for such studies have been listed in the Working Plan 2012-2014 (established according article 16(1) of the Ecodesign Directive) and this list includes "windows". Therefore a preparatory study has been requested by the Commission.

This preparatory study is to be executed according the Methodology for the Ecodesign of Energy-related Products (MEErP, 2011)[2] which identifies eight (1+7) tasks and shall allow stakeholder involvement. This report is the final report of Task 6 or “Options” of the study.

[2] http://www.meerp.eu/ VHK BV, Netherlands and COWI, Belgium: Methodology Study Ecodesign of Energy-related Products, MEErP Methodology Report, under specific contract SI2.581529, Technical Assistance for the update of the Methodology for the Ecodesign of Energy-using products (MEEuP), within the framework service contract TREN/R1/350-2008 Lot 3, Final Report: 28/11/2011

CHAPTER 2 INTRODUCTION

2.1. METHODOLOGY FOR ECODESIGN PREPARATORY STUDIES

This chapter introduces the objective of Task 6 of the full preparatory study. A full preparatory study follows the methodology for ecodesign of energy-related products established in 2011 (MEErP 2011) which itself is a succession of the former methodology dealing with energy-using products (MEEuP 2005) developed in 2005 to contribute to the creation of a methodology allowing evaluating whether and to which extent various energy-using products fulfil certain criteria according to Annex I and/or II of the Ecodesign Directive that make them eligible for implementing measures.

The full preparatory study is executed according to seven tasks, as described below:

Task 1 – Scope (definitions, standards and legislation);

Task 2 – Markets (volumes and prices);

Task 3 – Users (product demand side);

Task 4 – Technologies (product supply side, includes both BAT and BNAT);

Task 5 – Environment & Economics (Base case LCA & LCC);

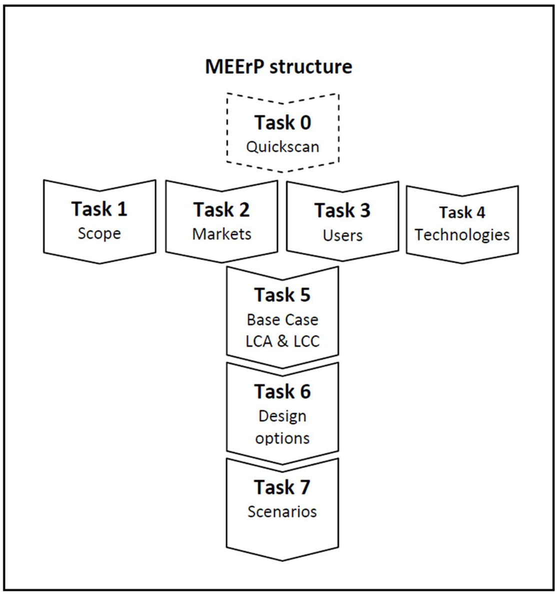
Task 6 – Design options;

Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis).

The MEErP structure makes a clear split between:

- Tasks 1 to 4 (product definitions, standards and legislation; economic and market analysis; consumer behaviour and local infrastructure; technical analysis) that have a clear focus on data retrieval and initial analysis;
- Tasks 5 (assessment of base case), 6 (improvement potential) and 7 (policy, scenario, impact and sensitivity analysis) with a clear focus on modelling.

Figure 1 MEErP structure



An optional Task 0 quick scan or first product screening has been introduced in the 2011 methodology for those product groups that are characterised by a large variety of products covered by a generic product group description. It was carried out for this study as well. The findings of this Task 0 are incorporated in the Task 4 report.

Tasks 1 to 4 can be performed in parallel, whereas Task 5, 6 and 7 are sequential.

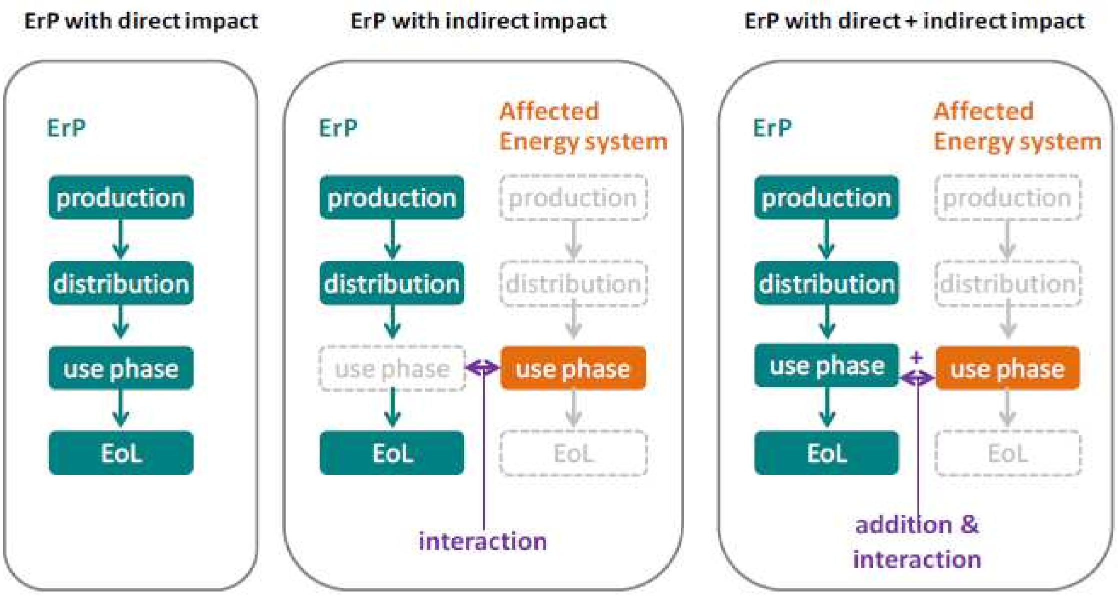
2.1.1. Energy related Products

The Directive 2009/125/EC defines an energy-related product as *"any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products covered by this Directive, which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently"*.

The impact on energy consumption during use of an energy-related product may take different forms and the MEErP methodology defined these as either direct and/or indirect impacts. The relevance of this lies in the analysis required and which should or should not include affected energy systems.

The MEErP introduced a grouping of energy related products into products with only direct impacts, only indirect impacts or both.

Figure 2 Three types of ErP (VHK, 2011)



Considering the above indicated grouping in MEErP of ErP products, windows are considered as an example of ErP with indirect impact.

2.2. MEErP – Details of work for Task 6

Task 6 identifies design options, their monetary consequences in terms of Life Cycle Cost for the consumer , their environmental costs and benefits and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT).

The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the total product life (purchase, running costs, etc.), while taking into account the manufacturers' R&D and investment costs for the purchase price development. The distance between the LLCC and the BAT indicates - in case a LLCC solution is set as a minimum target - the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably be more appropriate for promotion measures than for restrictive action. The BNAT indicates long-term possibilities and helps to define the exact scope and definition of possible measures.

The details of work for TASK 6 are described below. The TASK description is copied from MEErP 2011.

6 DESIGN OPTIONS

6.1 Options

Identify and describe (aggregated clusters of) design options to be taken into account (from Task 4, typically 4 to 8 design options are appropriate)

6.2 Impacts

Assess quantitatively the environmental improvement per option using the EcoReport tool. Compare the outcomes and report only on impacts that change significantly with the design options

6.3 Costs

Assess/ estimate price increase due to implementation of these design options, either on the basis of prices of products on the market and/or by applying a production cost model with sector-specific margins.

6.4 Analysis LLCC and BAT

6.4.1 Rank the individual design options by LCC (e.g. option 1, option 2, option 3;

6.4.2 Determine/ estimate possible positive or negative ('rebound') side effects of the individual design measures;

6.4.3 Estimate the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above side-effects;

6.4.4 Rank the accumulative design options; draw LCC-curves (1st Y-axis= LLCC, 2nd Y-axis= impact (e.g. energy), X-axis= options); identify the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT);

6.5 Long-term targets (BNAT) and systems analysis

Discussion of long-term technical potential on the basis of outcomes of applied and fundamental research, but still in the context of the present product archetype;

Discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs: Societal transitions, product-services substitution, dematerialisation, etc.

CHAPTER 3 DESIGN OPTIONS

3.1. THE OVERALL DESIGN

The different design options for commercially available windows are described in detail in TASK 4. A summary of these options is given below.

In the past, before the availability of IGU (with or without coating), often coupled and double windows were used. Due to the invention of IGUs it was no longer necessary to use coupled and double windows to achieve low thermal transmittance. Today single windows with a double or triple IGU are the most often used.

Single window

- One frame/casement combination plus one transparent filling element (single glass, double IGU, triple IGU) for tilt and turn windows;
- One frame and two sashes (at least one sliding); one transparent filling element in each sash (single glass, double IGU, triple IGU) for sliding windows;
- Shutter or blinds can be installed externally or internally, and also IGU with integrated blind are possible (however expensive);
- Easy to clean (two surfaces instead of four as with coupled or double window);
- Roof windows have some form of IGU as standard.

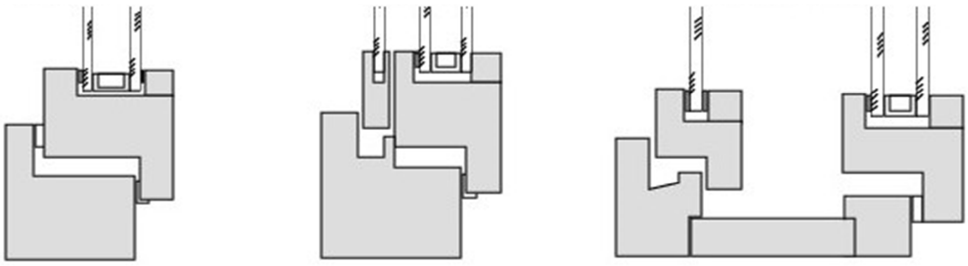
Coupled window

- One frame/two casements combination plus two transparent filling elements (single glass, double IGU, triple IGU), single glass usually installed in the outer sash, IGU usually installed in the inner sash; in principle it is also possible to have an IGU in the outer sash;
- The casements are coupled (but open able), therefore the operation of the casement (opening, closing) is just as easy as for the single window;
- Shutter or blinds can be installed externally or internally, but will usually be integrated between the sashes. The blind is protected from wind, rain and dirt, but can have similar performance as an exterior blind. Blinds must not be opened for the operation of the window;
- Coupled windows also allow high sound insulation;
- <u>*Coupled roof windows are available as a special product.*</u>

Double window

- Two complete windows installed in series, separated by an cavity of approx. 100 mm;
- Several possibilities for the combination for the glass; Exterior: Single glass or double IGU, Interior: double or triple IGU,
- For the operation of the window (opening, closing) the two sashes have to be operated one after another;
- The additional cavity allows the integration of blinds/sun shading devices, but in most cases blinds must be opened to open the window;
- Double windows allow very high sound insulations.

Figure 3 Construction of windows / sashes



From left to right:

a) single window
b) coupled window
c) double window

Note: The shown types of glazing's can change, e.g. triple instead of double IGU or double IGU instead of single glass.

3.2. Frame materials

The following frame materials are used for windows in general:

- Metal (aluminium, steel; with or without thermal break);
- Timber (wood);
- Plastics (PVC).

The frames for roof windows are made of wood, PU or PVC. The exterior of the frame is metal-clad as a standard.

The energy related characteristic of the frame is the thermal transmittance U_f. The thermal transmittance of frames can vary approximately between 6.0 W/(m^{2}K) ≤ U_f ≤ 0.8 W/(m^{2}K)[3]. For metal frames it is harder to achieve low U_f-values compared to frames made out of wood or plastics but comparable values are possible by adding thermal breaks. Furthermore, metal frames generally allow slim profiles resulting in lower frame fractions in general. The frame fraction is an important factor in the calculation of solar energy and light transmittance, when assuming constant outside dimensions.

Other materials used for windows frames may be glass fibre-reinforced plastics (GFRP) and also wood-polymer composite materials, but windows using such materials are fairly new to the window market and the experience-base is less developed (see also section 3.3 in TASK 4).

Developers experimenting with such window frame materials mention as benefits lower life cycle impacts when compared to windows using conventional materials, also because of the smaller **'frame fraction'** that may be obtained. However, also the more conventional frame materials are being improved to reduce frame fraction[4].

Windows made of GFRP are commercially available[5] but allegedly the significance to the window market is still considered to be very low.

Windows made of wood-polymer composites have been developed in the EU project "EXTRUWIN - Extruded window profiles based on an environmentally friendly wood-polymer composite material"[6] but have not yet resulted in a commercially available window product.

For this reason, and because the frame fraction is an element in the calculation of the energy performance of the window, no specific design options related to low frame fractions have been assessed.

3.3. Opening types

For windows there are several types of opening. Most common in Europe are the following:

- Tilt and turn windows
- Sliding windows

The opening type has some influence on the energy performance that can be achieved for a window, as it mainly influences the leakage rate, whereas glazing and frame properties may remain relatively untouched. Depending on the type, sliding windows can be as airtight as tilt-and-turn windows (vertical sliding).

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[3] Frames with a thermal transmittance of 0.6 already exist. Some roof lights can go as low as 0,29W/(m²K). Source: http://www.passiv.de/komponentendatabank

[4] An example of a conventional material with a slim profile is the "Mindow", an aluminium window profile with a very low frame fraction (still in development).

[5] For example: www.protecwindows.com → PRO TEC Xframe

[6] See: www.extruwin.eu/research.html

3.4. TRANSPARENT FILLING ELEMENTS

The main material (nearly 100%) for the transparent filling elements is soda lime glass.

The energy performance characteristics of transparent filling elements are the U_g value, the g-value and the light transmittance.

To reduce thermal losses through the glazing elements the U_g-value has to be reduced. This can be achieved by using double IGUs with Low-e coating and gas filling or triple glass units with Low-E coating and gas filling. At the same time, Low-E glass allows solar heat to pass into a building and warm the interior. Therefore the g-value should be as high as possible. Glazing products with low U_g-value and high g-value are therefore called thermally insulating glass.

Table 1 Typical constructions of thermally insulating glass used in windows

	Description	Typical cross section	Typical values		
			Thermal transmittance **U_g in W/m²K**	**Solar energy transmittance** **g**	**Light transmittance** **τ_v**
1	Single glass	Float glass 4-8 mm Laminated glass 6-10 mm	5,9	≈ 0.85	≈ 0.90
2	Double glass units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: - Gas filling: Air	≈ 2,7	≈ 0.78	≈ 0.82
3	Double Insulating glass Units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: ε_n = 0.03- 0.05 Gas filling: Air, Argon	≈1.1 - 1.3	≈ 0.62	≈ 0.80
4	Triple Insulating glazing Units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: ε_n = 0.03- 0.05 Gas filling: Air, Argon	≈0.6- 0.7	≈0.55	≈ 0.70

Solar control glass is glass designed to reduce or prevent solar heating of buildings and therefore reducing the cooling demand of buildings. This can be achieved by using special reflective coatings or by tinting the exterior pane of an IGU so that the g-value is reduced. Also for solar control glass very low U_g-values can be achieved.

Part of the IGU's are spacers, for which 'warm edge' variants (see TASK 4) are developed.

3.5. SHUTTERS/SUN SHADING DEVICES

When assessing the energy performance of windows the key focus is on the window itself. However, shading devices are a relevant “add on” that support a dynamic envelope, reduce energy consumption and increase comfort in buildings, when properly activated:

– When fully closed, reduce the thermal transmittance of the window by creating a cavity;

– When fully closed, reduce the solar gains of the window by reflecting/absorbing of solar radiation and creating a cavity

- When fully closed, block light transmission thus increasing the need for artificial lighting.

The characteristic of the shutter/blind that has to be considered in the calculation of the thermal transmittance of the window U_w is the additional thermal resistance ΔR of the shutter/additional cavity between shutter[7] and window. The ΔR value of a shutter depends on:

1. the thermal resistance of the shutter itself and
2. the airtightness of the shutter.

The g_t-value is the characteristic taken into account for the evaluation of the solar gains of a window with an additional shutter/blind. To reduce the cooling demand, low g_t values are necessary. In general external blinds have a better thermal performance than internal blinds.

3.6. Summary

3.6.1. Energy related options

With the existing technologies, windows can be produced with a huge variety in the relevant energy related characteristics. The options for window design can be represented on the basis of the existing 11 different façade window constructions (base cases) defined in TASK 5. Of course many more configurations than the eleven presented below exist, but these types are considered to represent a good overview of available types, including products offering the highest energy performance.

Table 2 Window constructions with different design options used for the LCCA

No.	U_w in W/m^2K	g	Description
FAÇADE windows			
1	5.8	0.85	Single glazing; Frame: even no or bad thermal break
2	2.8	0.78	Double IGU; Standard frame (wood, PVC, Metal)
3	1.7	0.65	Double IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)
4	1.3	0.60	Double IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)
5	1.0	0.55	Triple IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)
6	0.8	0.60	Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Improved frame (wood, PVC, Metal)
7	1.0	0.58	Single and Double IGU with Low-e coating and argon filling, thermally improved spacer; Coupled window(wood, PVC, Metal)
8	0.6	0.47	2 Double IGU with Low-e coating and argon filling, thermally improved spacer; Double window (wood, PVC, Metal)
9	2.8	0.35	Double IGU solar control; Standard frame (wood, PVC, Metal)
10	1.3	0.35	Double IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)
11	0.8	0.35	Triple IGU solar control with Low-e coating and argon filling, thermally improved spacer; Improved frame (wood, PVC, Metal)
ROOF windows			
roof_3	1.7	0.60	Double IGU with Low-e coating and argon filling; Frame metal-PVC/PU or metal-wood (Uw vertical 1.3)
roof_4	1.1	0.50	Triple IGU with Low-e coating and argon filling; thermally improved spacer; Frame metal-PVC/PU or metal-wood (Uw vertical 1.0)
roof_5	0.9	0.50	Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Frame metal-PVC/PU or metal-wood (Uw vertical 0.8)
roof_6	1.7	0.35	Double IGU with Low-e coating and argon filling and solar control glazing; Standard frame metal-PVC/PU or metal-wood (Uw vertical 1.3

For roof windows the same configurations (for Uw and g-value etc.) were used, but then applied in an inclined roof, with a slope of average 40º, which increases the factor B and Y (related to solar irradiance) considerably (see TASK 7, section 4.2.2).

[7] The term shutters is to be understood comprising all kinds of solar shading devices, including blinds (if used externally).

To consider the impact of sun shading in the analysis, an external shutter was defined with the following energy related characteristics:

- Additional thermal resistance $\Delta R = 0.17\ m^2K/W$
- Solar shading coefficient $F_C = 0.1$

The boundary conditions (set points for activation of solar shading device) are as defined in TASK 4 (also basis for TASK 7).

The window constructions and the external shutter are identical with the products in TASK 4 used for the calculation to identify the BAT product.

Windows with specific construction characteristics that are not directly energy related, such as sound insulation, safety and security, burglary resistance and fire resistance, are not represented as base cases. However, the energy balance of windows with such features can be affected and this aspect should be taken into account when setting requirements (subject to TASK 7).

3.6.2. Non-energy related options

The TASK 5 analysis shows that energy 'consumption' during the use-phase is the dominant environmental parameter (although paradoxally the energy 'consumption' can reduce to zero or even become negative, making the window a net energy supplier). Nonetheless, several stakeholders have asked for (at least a qualitative) consideration of non-energy related design options.

These non-energy related design options may address the following aspects of windows. The options were based on JRC studies into resource efficiency [8]:

- durability (extension of product life);
- re-use ability / recyclability / recoverability (also as 'benefit rates');
- presence of hazardous substances;
- recycled content.

It must be noted that the methodological approach for these aspects is still being developed, and should be looked at in the context of Product Environmental Foot printing as well, which sets out to describe product category rules for life cycle assessment.

Regarding durability, the TASK 7 Scenario analysis shows the outcome of extending the average window product life from 40 years to 50 years. The result is negative, as the energy savings are reduced because of slower replacement of old windows, and this does not outweigh the reduction in material inputs.

Regarding re-usability, the current practice shows that re-use occurs very rarely and almost never in the original application (as fenestration element in building envelope). Furthermore, if used as building envelope element it would again slow down the application of modern windows with possibly a better energy performance (as argued above, in 'durability').

Regarding recyclability and recoverability, the current practice shows huge variations in recycling which cannot be explained by the mechanical or physical properties of the window. It appears that the handling of construction and demolition waste is of particular importance to the overall recycling rates, and the window design is much less of influence in this (it does show that windows using materials with higher value, such as aluminium, have a higher chance of being recovered). Furthermore it must be noted that any measure regarding recyclability actually addresses windows that reach their end-of-life in 40 years from now (year 2055 on average). Making predictions on end-of-life treatment options over such a time period is risky at minimum. The methodological immaturity, the extremely long time scale and the pivotal importance of handling of construction and demolishment waste makes identification of measures extremely demanding and unfit for current regulatory practice. Still, this does not mean that no effort should be made to increase the recycling rates of windows, especially those made of plastic (recycling of aluminium is occurring at a large scale, recycling of wooden windows remains problematic and only thermal recovery is believed to be a viable option).

Regarding 'presence of hazardous substances' most manufacturers (in particular the system houses) are working to eliminate substances that have been identified as hazardous or restricted under REACH. Cadmium and lead is phased out in PVC windows, Cr6+ as surface (pre)treatment is phased out in aluminium production, wood preservation applied nowadays is either avoided (by proper selection of wood species) or relatively unproblematic (boric acid capsules in limited areas).

[8] F. Ardente, F. Mathieux. *Development of guidance documents*. European Commission. Joint Research Centre. Institute for Environment and Sustainability. Deliverable 3 of the project "Integration of resource efficiency and waste management criteria in European product policies – Second phase", September 2012.

Regarding 'recycled content' (here interpreted as the use of post-consumer materials in the product) current practice shows this is already occurring, albeit on a limited scale. EPPA currently recycles some 14% (see TASK 4 End-of-Life) of the PVC windows discarded. In general it is assumed that aluminium products contain some 25% post-consumer aluminium (MEErP 2011, Part 2 report). Most of this post-consumer aluminium however ends up in castings (some 85%) and a much lower share ends up in wrought and sheet aluminium (some 11%), often because of requirements regarding surface quality and finishing and because mixed aluminium scrap from different markets can more easily be incorporated into casting alloys.

Certain manufacturers boast a higher than average recycled content of their products, up to 85% for certain aluminium frames, but this is mainly realised by creation of take-back schemes. Take-back schemes are problematic under Ecodesign as it introduces aspects that may not be able to be measured at the product itself (assuming that the difference between windows with average and higher than average recycled content cannot be shown by analysis of the physical product itself). A different approach, similar to the WEEE Directive, would be necessary.[9]

Already several manufacturers are working on reduction of material inputs, but an important main driver for this is the improvement of the frame fraction ('slimmer frames') which – if applied appropriately, i.e. the frame losses should not increase – may result in a better energy performance (this depends on the balance between solar gains and thermal losses and heat transfer parameters of glazing and frame etc.). The 'slimming' of the frame will not be assessed as a design option as it is poorly enforceable through legislative measures, and already addressed by market forces.

[9] For windows, the recycled metal content is an incomplete indicator of its environmental performance since, due to scrap supply shortage compared to the demand, orienting the scrap towards one market diverts it from other markets. It may help to create demand for recycled material (demand increases) but then supply must be able to match up, which means increasing recycling rates of products.

CHAPTER 4 IMPACTS

4.1. Impacts

4.1.1. Energy performance impacts

The life cycle phases of the products have been described in TASK 5, covering the production, use and end-of-life phase of the base cases.

The use-phase impacts have been modelled on the basis of the energy balance of the window product (base cases). The performance is assessed on the basis of the ABC/XYZ values as established in TASK 7 scenario analysis to achieve a maximum congruence of the energy related impacts and the economic impacts (life cycle costs, etc.) – See TASK 7 for details. The ABC/XYZ values have been weighted for sector window area (e.g. multifamily versus single family) and average U_{env} (average between high and low values assumed) and are a mixture of 'single room' and 'single family house' based values (as both apartments and family houses are covered). The values for the roof window are based on the 'single room' values only. XYZ values used for the cooling performance assume ventilative cooling to take place.

This also means that these values cannot and should not be compared to performance values as established in TASK 4 Technology, as the underlying method is different. Please see the relevant section in TASK 7 for an explanation between the adiabatic method (as applied in TASK 4) and the ABC/XYZ method (as applied in TASK 3, 5, 6 and 7).

Different to TASK 3, 5 and TASK 7 (that all rely on a similar set of ABC/XYZ values), the C and Z values are not corrected. This is because this TASK 6 will also consider the effects of changing window covering (shutter) costs and for this we assume that the window covering is used optimally.

Table 3 ABC and XYZ values used for assessment, per climate condition

Façade window orientation	Uni			N			E			S			W		
climate condition	North	Central	South	North	Central	South	North	Central	South	North	Central	South	North	Central	South
A	98	61	18	103	65	22	98	62	18	92	57	15	98	61	18
B	225	196	193	119	116	94	211	177	187	352	300	303	217	191	187
C 22/6	0.35	0.37	0.42	0.35	0.37	0.42	0.35	0.37	0.42	0.35	0.37	0.42	0.35	0.37	0.42
X	0.3	0.1	-4.3	0.1	-0.1	-4.5	0.4	0.1	-4.3	0.4	0.0	-4.2	0.3	0.1	-4.3
Y	17	44	304	6	26	161	21	55	373	20	45	307	19	48	375
Z	0.69	0.54	0.66	0.04	0.00	0.00	0.72	0.60	0.77	0.79	0.65	0.74	0.77	0.64	0.77
Roof windows orientation	Uni			N			E			S			W		
climate condition	North	Central	South	North	Central	South	North	Central	South	North	Central	South	North	Central	South
A	86	49	9	98	58	18	85	50	8	76	39	3	86	49	7
B	156	150	90	121	105	79	148	151	104	197	189	78	158	155	99
C 22/6	0.35	0.36	0.38	0.35	0.36	0.38	0.35	0.36	0.38	0.35	0.36	0.38	0.35	0.36	0.38
X	1.3	1.2	-3.0	0.6	0.6	-3.8	1.5	1.3	-3.1	1.8	1.7	-2.2	1.2	1.3	-3.0
Y	56	127	659	24	88	512	63	141	678	84	158	770	54	123	678
Z	0.75	0.75	0.88	0.33	0.59	0.81	0.69	0.73	0.89	0.81	0.81	0.89	0.85	0.81	0.91

The calculated energy performances, for three different climate conditions, and for windows with or without an external shutter are presented below.

Table 4 Windows energy performance for heating and cooling, with/without shutters, per climate condition

No.	U_w in W/m^2K	g	Air tightness	Energy use in kWh/(m^2 a) related to m^2 window area								
				Climate condition North			Climate condition Central			Climate condition South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
FAÇADE WINDOWS												
without shutter												
1a	5.8	0.85	2	574	8	582	324	25	349	15	212	227
2a	2.8	0.78	3	198	8	206	93	24	116	-46	180	134
3a	1.7	0.65	4	80	7	87	24	20	44	-54	146	92
4a	1.3	0.60	4	48	7	55	7	18	25	-55	134	79
5a	1.0	0.55	4	27	6	33	-5	17	12	-53	122	69
6a	0.8	0.60	4	-1	7	6	-24	18	-5	-64	132	68
7a	1.0	0.58	4	22	7	29	-9	18	9	-58	128	71
8a	0.6	0.47	4	0	5	6	-18	14	-4	-50	103	53
9a	2.8	0.35	3	266	3	269	152	10	162	12	89	100
10a	1.3	0.35	4	88	4	92	41	11	52	-21	81	60
11a	0.8	0.35	4	39	4	43	10	11	21	-30	79	49
with shutter												
1b	5.8	0.85	2	475	2	477	259	13	272	-7	107	100
2b	2.8	0.78	3	167	3	170	72	12	85	-53	85	31
3b	1.7	0.65	4	67	3	69	16	11	26	-57	69	12
4b	1.3	0.60	4	40	3	43	1	10	11	-57	64	7
5b	1.0	0.55	4	22	3	24	-8	9	1	-55	59	4
6b	0.8	0.60	4	-4	3	-1	-26	10	-16	-65	62	-3
7b	1.0	0.58	4	17	3	20	-12	10	-2	-59	61	2
8b	0.6	0.47	4	-2	2	1	-19	8	-11	-50	51	1
9b	2.8	0.35	3	235	1	236	131	6	138	5	53	58
10b	1.3	0.35	4	80	2	81	36	6	42	-23	46	23
11b	0.8	0.35	4	35	2	37	8	7	15	-31	43	13
ROOF WINDOWS												
without shutters												
03	1.7	0.6	4	94	21	116	28	51	79	-21	283	262
04	1.1	0.5	4	54	18	72	9	43	52	-20	235	214
05	0.9	0.5	4	36	18	55	-1	43	43	-22	234	212
06	1.7	0.35	4	122	11	133	54	29	83	-5	167	162
with shutters												
03	1.7	0.6	4	83	7	89	21	18	39	-22	79	56
04	1.1	0.5	4	48	6	55	6	16	22	-21	72	51

05	0.9	0.5	4	33	7	39	-3	16	14	-22	71	49
06	1.7	0.35	4	110	4	114	48	12	60	-7	65	59

The disposal phase has also been described in TASK 4 and specified as Ecoreport inputs in TASK 5. The improvement options (base cases) identified for windows (see Chapter 3) correspond to the base cases described in TASK 5. The main differences that will be assessed in this TASK 6 are related to differences in energy performance.

4.1.2. Other impacts

As the differences in material composition per window type are already presented in TASK 5 and this TASK 6 is only to report on impacts that change significantly with the design options, no additional analysis using Ecoreport is performed.

The impact of increased durability (longer product life) has been assessed quantitatively in TASK 7. Other non-energy aspects are dealt with qualitatively in TASK 7.

CHAPTER 5 COSTS

5.1. COSTS FOR WINDOWS

The costs of windows have been assessed as part of TASK 2.

The stated average costs (indicative for period 2010 – 2015 and representing the combined average of EU28 prices) are including the installation of the window and VAT, prices are per 1 m^2 window.

Table 5 Representative costs for different design options of windows

No.	U_w in W/m^2K	g	Description	Costs in €/m^2 (incl. installation, incl. VAT)
			FAÇADE WINDOWS	
1	5.8	0.85	Single glazing; Frame: even no or bad thermal break	154
2	2.8	0.78	Double IGU; Standard frame (wood, PVC, Metal)	234
3	1.7	0.65	Double IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)	255
4	1.3	0.60	Double IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)	256
5	1.0	0.55	Triple IGU with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)	298
6	0.8	0.60	Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Improved frame (wood, PVC, Metal)	403
7	1.0	0.58	Single and Double IGU with Low-e coating and argon filling, thermally improved spacer; Coupled window(wood, PVC, Metal)	370
8	0.6	0.47	2 Double IGU with Low-e coating and argon filling, thermally improved spacer; Double window (wood, PVC, Metal)	510
9	2.8	0.35	Double IGU low g-value solar control ; Standard frame (wood, PVC, Metal)	288
10	1.3	0.35	Double IGU low g-value solar control with Low-e coating and argon filling; Standard frame (wood, PVC, Metal)	299
11	0.8	0.35	Triple IGU low g-value solar control with Low-e coating and argon filling, thermally improved spacer; Improved frame (wood, PVC, Metal)	456
			ROOF WINDOWS	
roof_3	1.7	0.60	Double IGU with Low-e coating and argon filling; Frame metal-PVC/PU or metal-wood	480
roof_4	1.1	0.50	Triple IGU with Low-e coating and argon filling; thermally improved spacer; Frame metal-PVC/PU or metal-wood	708
roof_5	0.9	0.50	Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Frame metal-PVC/PU or metal-wood	913
roof_6	1.7	0.35	Double IGU with Low-e coating and argon filling and solar control glazing; Standard frame metal-PVC/PU or metal-wood	578

The reference life cycle cost calculation is based on the above mentioned prices (for 1m^2 of a standard sized window, which includes installation and VAT). As it was not possible to collect an exhaustive cost data set for windows, a sensitivity analysis showing the effects of reduced and increased costs of windows (respectively 0.75 and 1.25 mark-up factor) has been added.

The product life is, for the reference LCC calculation, set at 40 years. As windows may show a huge spread in (average) product life, a sensitivity analysis has been added, showing the effects on the calculated LCC of a reduced life (30 years) and a longer life (50 years). Also glazing unit or pane change has been included in the data for LLCC calculations for windows, whereby if window life is 30 years, no pane change is assumed, and if window life is 40 or 50 years it is assumed that pane change occurs once.

5.2. COSTS FOR WINDOW COVERING (SHUTTERS, SUN SHADING)

The average costs for window covering such as shutters and sun shading devices were also assessed in TASK 2. The results are shown below.

Table 6 Representative costs for typical shading products

Solar shading devices	Av. price	Drive	Typical surface (m)	Avg euro/m2
Awnings (Folding arm, terrace, …)	3 000 €	(motorised)	W 6,0 x H 3,5	143
External roller blinds (markisolette)	600 €	(motorised)	W 1,5 x H 2,0	200
External venetian blinds	600 €	(motorised)	W 1,5 x H 2,0	200
Panel shutters (sliding, hinged, …)	400 €	(manual)	W 1,2 x H 1,5	133
	1 600 €	(motorised)	W 1,2 x H 1,5	533
Roller shutters	400 €	(motorised)	W 1,2 x H 1,5	133
Internal blinds (made to measure)	150 €	(manual)	W 1,2 x H 1,8	69
	400 €	(motorised)	W 1,2 x H 1,8	185

As we cannot model this many variants of solar shutters, we've selected a shutter cost of **125 euro/m^2** (for a window of 1 m^2) to be used reference life cycle cost calculation. This represents a low-cost shutter solution (price range minimum is 90 euro/m^2). A sensitivity analysis shows the effects of reduced and increased costs of shutters (respectively **75 and 200 euro/m^2**).

5.3. OTHER COST DATA

The energy balance is expressed as the annual heating or cooling demand for 1m^2 of window. The heating demand can be translated into heating costs by assuming an efficiency of the system supplying the demand and an energy rate.

The same can be done for the cooling demand, whereby it should be noted that in practice not every cooling demand leads to cooling costs, for instance if the building has no cooling system and/or higher indoor temperatures are allowed. Of course, it could be that windows that allow relatively large solar gains, thereby more quickly leading to overheating situations, may lead to extra costs related to purchasing of artificial cooling equipment. This effect however could not be incorporated into the cost analysis.

For the calculation of life cycle costs, both heating and cooling demand are expressed as heating and cooling costs, using the following rates and efficiencies.

Table 7 Energy rate and system efficiency

	Energy rate	Comment
Heating	0.07/kWh_fuel	partly based on MEErP 2011, with additional analysis of Eurostat 2015 data. See also analysis in Task 7 Scenario's
Cooling	0.18/kWh_electricity	
	System efficiency (reference)	**Comment**
Heating	59%	Based on Ecodesign/Energy Labelling Impact Accounting (Source: VHK 2014)
Cooling	311%	

A sensitivity analysis is added to analyse the effects of different energy rates or system efficiencies.

CHAPTER 6 ANALYSIS LLCC AND BAT

6.1. Analysis of LLCC and BAT

Base-Case Life Cycle Costs for consumer

The basic LCC formula is:

LCC = PP + PWF * OE + EoL,

where

LCC is Life Cycle Costs to end-users in €,

PP is the purchase price (including installation costs) in €,

OE is the annual operating expense in €

PWF (Present Worth Factor) is

$$PWF = \frac{1 - \frac{1}{(1+d)^N}}{d}$$

in which

N is the product life in years and

d is the discount rate in %

and in case *d=0* the value of *PWF=N*

EoL: End-of-life costs (disposal cost, recycling charge) or benefit (resale).

During the preparatory studies it became apparent that the price increase of the operating expense plays an important role and –as argued by consultants—should be an integral part of the LCC. As a result it is proposed to use the following formula for PWF

$$PWF = 1 - \left(\frac{1+e}{1+d}\right) \cdot \left[1 - \left(\frac{1+e}{1+d}\right)^N\right]$$

where

e is the aggregated annual growth rate of the operating expense (a.k.a. 'escalation rate', in €) and

in case *d=e* (mathematically undefined) ***PWF= N***

The discount rate is by default (for EC studies) 4%. The external damages escalation rate is around 4% and the inflation-corrected energy rate growth rate is - at the moment - also in the order of 3-4%. This means, for cases where repair and maintenance costs are insignificant, the assumption of a case where r=p and thus PWF=1 would result in a negligible error.

As a result, the LCC formula for MEErP Task 5 and 6 the LCC can be simplified to

LCC= PP + N*OE + EoL

Note that this simplified formula cannot be applied if there is a significant (>1% point) difference between discount rate r and the aggregated growth rate of the operating expense.

6.1.1. Ranking of individual design options

Although required by the MEErP, the identification of the impacts (energy, costs) of individual design options would not be meaningful as in the case of windows, the process of selecting the combination of individual options is already performed by the market. The combined options are reflected through the identification of 11 base cases, which represent different performances achievable by windows available in the market.

Of course, the method based on ABC and XYZ values in principle allows assessment of other combinations of U_W and g (and other main characteristics).

6.1.2. POSSIBLE SIDE ('REBOUND') EFFECTS OF INDIVIDUAL OPTIONS

The MEErP methodology requires consideration of possible 'rebound' effects[10], which may occur at product technical level (one improvement affects another in price or energy performance) or at consumer expenditure level.

At technical level it is assumed that possible side effects of the combination of individual design options are reflected in the energy performance of the window and the purchase cost in an integral manner. No technical 'rebound' effects of the individual design measures need to be taken into account.

Where the rebound-effect occurs on consumer expenditure level one can argue that replacing windows by more efficient windows allows consumers to spend less on heating bills and consume more of the product or spend more on other (possibly more energy intensive) activities , possibly resulting in a net environmental loss. As regards windows it is not expected that lower heating bills result in more purchasing of windows (it may affect the replacement rate, but it is not expected to affect the total amount of windows installed in buildings).

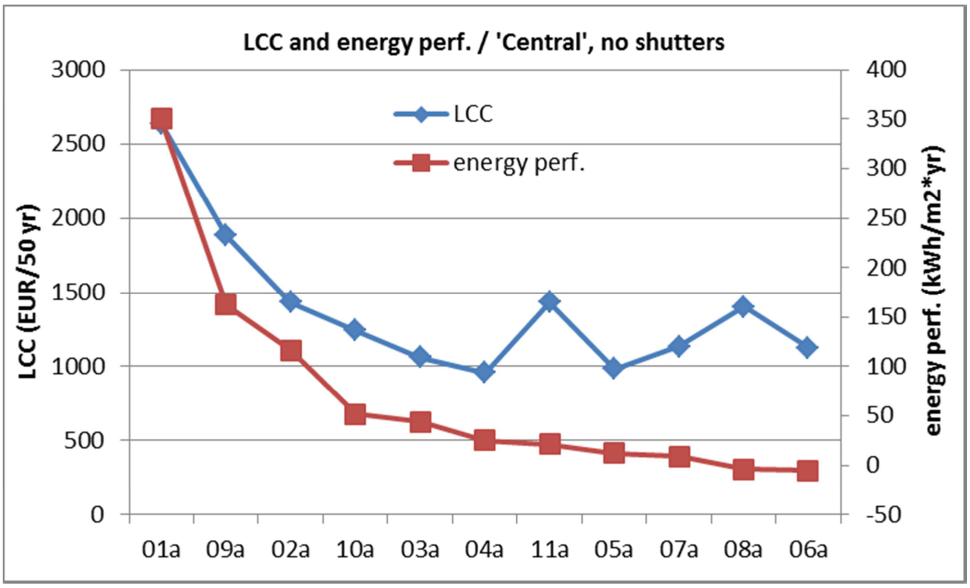
6.1.3. RANKING OF COMBINED OPTIONS

As shown in TASK 3, TASK 4 and Chapter 4 'Impacts' of this TASK 6 report, one can calculate for each base case window an energy performance, which is the combined effect of energy losses (outgoing energy such as heat loss) and energy gains (incoming energy, such as solar heat gain). The calculation of the energy performance must consider certain boundary conditions are defined as well. An explanation of these boundary conditions is given in TASK 3 and TASK 4.

The terms of reference of the study ask for provision of life cycle cost curves. The set of curves below provides this data, but it should be noted that these curves apply to the climate condition designated as 'Central' and a window with 30 year average product life. Showing curves for all other possible permutations (11 base cases, 3 climate conditions, 2 seasons, and 2 shutter options) would not make interpretation easier.

The x-axis is the design option (window type) as presented in Table 2 and Table 4 ('a' is without shutter, 'b' is with shutter). The y-axis is the life cycle costs in euro per 50 yrs. (red) and the energy balance in kWh/m2/yr. (blue).

Figure 4 Energy balance and LCC of window without shutters (Central climate condition, 30yr life)



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10 **ec**.europa.**eu**/environment/**eus**sd/pdf/**rebound**_effect_report.pdf

Figure 5 Energy balance and LCC of window with shutters (Central climate condition, 30yr life)

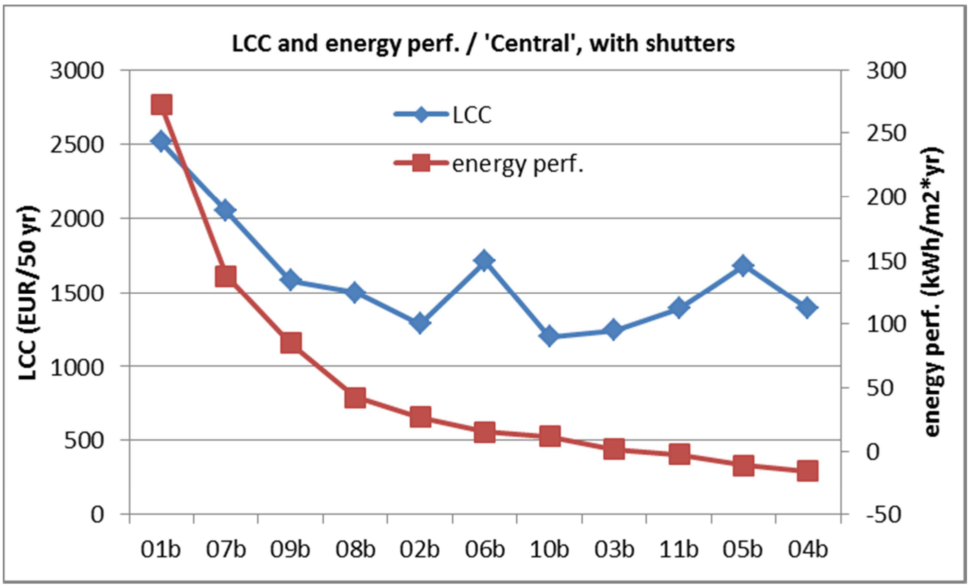
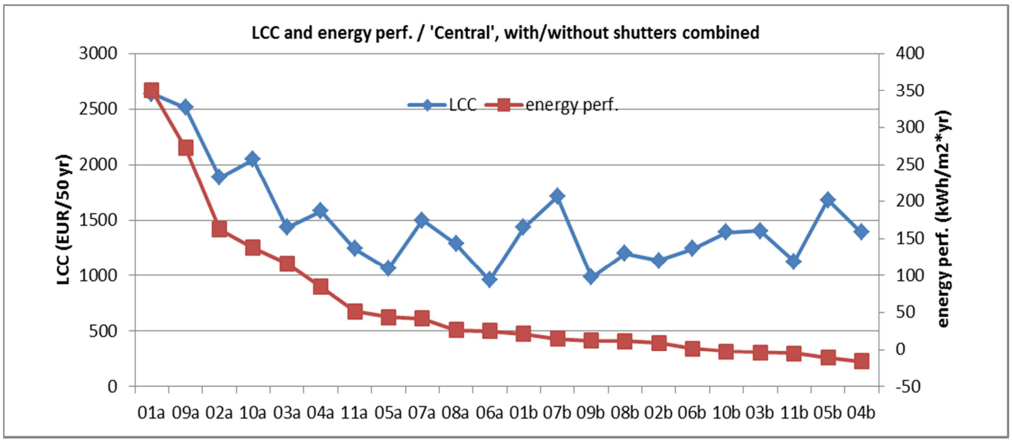


Figure 6 Energy balance and LCC of window with & without shutters (Central climate condition, 30yr life)



6.1.4. Least Life Cycle Cost (LLCC) and Best available technology (BAT)

In this TASK 6 the least life cycle cost point (LLCC) and the best available technology (BAT) have to be identified.

The BAT as identified before in TASK 4 Technology, was established using the "adiabatic approach" applied to a single room and family house.

The approach in this TASK 6 report is different as here the performance is based on a performance calculation using ABC and XYZ values as established in TASK 7 for heating and cooling. This allows establishing a calculation basis for performance that can more easily be tuned towards the characteristics of the stock (difference between apartments and family houses), changes in boundary conditions (with or without ventilative cooling) and/or changes in assumed values themselves (change C or Z if shutter use is assumed differently).

In doing so, and by using similar ABC/XYZ values throughout TASK 3 (User analysis), TASK 5 (environmental analysis), TASK 6 (cost analysis) and TASK 7 (overall EU impacts, as calculated using scenario's) the number of possible performances that are being used for assessment is reduced, thereby increasing overall consistency. The only difference is that in TASK 6 the C and Z values are not corrected. We note that the method using ABC/XYZ values may be slightly less exact than the adiabatic model used in TASK 4, but the increased flexibility of the approach using ABC/XYZ makes up for this.

→ Best Available Technology

The best available technology (BAT), defined as the combination of options where most energy savings can be reached irrespective of economic considerations, is the most right point on the 'Energy performance' curve (lowest values).

The life cycle cost analysis is limited to windows in the residential sector, as the boundary conditions are expected to be more representative for the average application.

Facade windows

The energy performances of the 11 window types has been calculated using the ABC/XYZ approach described in TASK 7 (multifamily dwellings using ABC/XYZ values based on 'single room model', and single family dwellings using ABC/XYZ values based on 'family house model').

The table below shows in green cells the lowest values (best performances) found for windows with and without window covering.

Table 8 Best available technology for façade windows (uniform orientation)

No.	U_w in W/m^2K	g	Air tight-ness	Energy use in $kWh/(m^2 a)$ related to m^2 window area								
				North			Central			South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
without shutters												
01a	5.8	0.85	2	574	8	582	324	25	349	15	212	227
02a	2.8	0.78	3	198	8	206	93	24	116	-46	180	134
03a	1.7	0.65	4	80	7	87	24	20	44	-54	146	92
04a	1.3	0.6	4	48	7	55	7	18	25	-55	134	79
05a	1	0.55	4	27	6	33	-5	17	12	-53	122	69
06a	0.8	0.6	4	-1	7	6	-24	18	-5	-64	132	68
07a	1	0.58	4	22	7	29	-9	18	9	-58	128	71
08a	0.6	0.47	4	0	5	6	-18	14	-4	-50	103	53
09a	2.8	0.35	3	266	3	269	152	10	162	12	89	100
10a	1.3	0.35	4	88	4	92	41	11	52	-21	81	60
11a	0.8	0.35	4	39	4	43	10	11	21	-30	79	49
with shutters												
01b	5.8	0.85	2	475	2	477	259	13	272	-7	107	100
02b	2.8	0.78	3	167	3	170	72	12	85	-53	85	31
03b	1.7	0.65	4	67	3	69	16	11	26	-57	69	12
04b	1.3	0.6	4	40	3	43	1	10	11	-57	64	7
05b	1	0.55	4	22	3	24	-8	9	1	-55	59	4
06b	0.8	0.6	4	-4	3	-1	-26	10	-16	-65	62	-3
07b	1	0.58	4	17	3	20	-12	10	-2	-59	61	2
08b	0.6	0.47	4	-2	2	1	-19	8	-11	-50	51	1
09b	2.8	0.35	3	235	1	236	131	6	138	5	53	58
10b	1.3	0.35	4	80	2	81	36	6	42	-23	46	23
11b	0.8	0.35	4	35	2	37	8	7	15	-31	43	13
a = Without shutters												
b = With shutters												

As regards heating performance without shutters window type 6 is consistently the highest performing window. For cooling performance the best window is equipped with solar control glazing, but the optimum U values changes per climate condition.

For the combined annual performance the best window without shutters changes from type 8 in North, type 6 in Central to type 11 in South. With shutters the best performing type is type 6.

Roof windows

The table below shows in green cells the lowest values (best performances) found for roof windows with and without window covering.

Table 9 Best available technology for roof windows

	U_w in W/m^2K (40º)	g	ΔR in W/(m2K)	Q100 [m3/(hm)]	Ff [-]	Energy use in $kWh/(m^2 a)$ related to m^2 window area		
						North	Central	South

						Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
without shutters														
01	6.6	0.85	0.17	27	0.3	597	23	620	304	66	370	19	417	435
02	3.2	0.78	0.17	9	0.3	231	26	257	98	65	163	-16	371	355
03	1.7	0.6	0.17	3	0.3	94	21	116	28	51	79	-21	283	262
04	1.1	0.5	0.17	3	0.3	54	18	72	9	43	52	-20	235	214
05	0.9	0.5	0.17	3	0.3	36	18	55	-1	43	43	-22	234	212
06	1.7	0.35	0.17	3	0.3	122	11	133	54	29	83	-5	167	162
with shutters														
01	6.6	0.85	0.17	27	0.3	492	1	493	242	15	258	7	111	118
02	3.2	0.78	0.17	9	0.3	197	6	203	78	19	98	-20	94	74
03	1.7	0.6	0.17	3	0.3	83	7	89	21	18	39	-22.4	79	56
04	1.1	0.5	0.17	3	0.3	48	6	55	6	16	22	-21	72	51
05	0.9	0.5	0.17	3	0.3	33	7	39	-3	16	14	-22.4	71	49
06	1.7	0.35	0.17	3	0.3	110	4	114	48	12	60	-7	65	59

For roof windows the best heating performance (with and without shutters) is provided by roof window type 5 (U_W 0.9, g 0.5) in condition North and Central. In South the best heating performance is by roof window type 5 (U_W 0.9, g 0.5). The best cooling performance is always delivered by roof window type 6 (U_W 1.7, g 0.35).

The best combined annual performance is provided by window type 5 in North and Central conditions and in South type 6 (no shutter) or type 5 (with shutter).

6.2. LEAST LIFE CYCLE COSTS FACADE WINDOWS

The least life cycle cost (LLCC), defined as the economic optimum, is reached where the 'Life cycle cost' curve is lowest.

The calculation of life cycle costs requires as inputs the purchase costs, including installation costs (and VAT as the calculation applies to residential products mainly), maintenance costs, energy costs and disposal costs. These costs have been further explained in Chapter 5 of this report.

The following assumptions are underlying the calculation of life cycle costs:

1. The complete calculation refers to 1 m2 window. It is based on calculations using standard window size and then recalculated to 1m2 window;
2. The window product life is set at 40 years. However, the functional unit for the calculation of LCC (in other words: the period over which the service is assessed) is set at 50 years. A shared functional unit allows a comparison of LCC of changes in product life (must be on basis of same performance unit, e.g. 'x' years of service);
3. The costs of shutters for windows type 'b' are estimated to be 125 euro per m2 window;
4. A positive energy balance for 'cooling' is calculated as a cooling need, which is met by an air conditioning appliance. This assumption is debatable, as not each cooling need will lead to cooling costs, for instance if the building has no AC system, or higher indoor temperatures are accepted: See also the LCC data for zero cooling costs in the sensitivity analysis;
5. Heating and cooling efficiency and costs (energy rates) are as explained as in Chapter 5 of this report;
6. Glazing unit replacement has been added to the cost analysis as well, assuming a glazing unit product life of 20 years.

The table on the next page presents the calculated life cycle costs for façade windows for three climate conditions North, Central and South, for both windows with and without shutters. The columns present the calculated costs (energy costs per year, cooling costs per year, overall functional unit life cycle costs (over 50 years).

Table 10 Heating/cooling/life cycle costs for North, Central and South condition

						North			Central			South		
		Purchase costs, incl. installation, incl. VAT	Maintenance costs (euro/yr)	Purchase over functional unit, incl.VAT	PWF	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit
01a Uw 5.8 / g 0.85	0	154	7.10	189	50	64	0.5	3771	36	1.5	2426	2	12.3	1242
02a Uw 2.8 / g 0.78	0	234	8.18	286	50	22	0.5	1825	10	1.4	1281	-5	10.4	957
03a Uw 1.7 / g 0.65	0	255	8.48	313	50	9	0.4	1203	3	1.1	929	-6	8.5	857
04a Uw 1.3 / g 0.6	0	256	8.49	314	50	5	0.4	1029	1	1.1	829	-6	7.8	821
05a Uw 1 / g 0.55	0	298	9.06	366	50	3.0	0.4	986	-1	1.0	840	-6.0	7.1	873
06a Uw 0.8 / g 0.6	0	403	10.49	494	50	-0.1	0.4	1035	-3	1.1	939	-7.1	7.6	1044
07a Uw 1 / g 0.58	0	370	10.04	454	50	2.5	0.4	1098	-1	1.0	957	-6.4	7.4	1007
08a Uw 0.6 / g 0.47	0	510	11.94	625	50	0.0	0.3	1239	-2.0	0.8	1162	-5.6	6.0	1243
09a Uw 2.8 / g 0.35	0	288	8.92	353	50	30	0.2	2291	17	0.6	1676	1	5.1	1120
10a Uw 1.3 / g 0.35	0	299	9.07	366	50	10	0.2	1320	5	0.6	1079	-2	4.7	936
11a Uw 0.8 / g 0.35	0	456	11.20	559	50	4	0.2	1346	1	0.6	1208	-3	4.5	1179
01b Uw 5.8 / g 0.85 / shutte	1	279	8.80	342	50	53	0.1	3440	29	0.8	2266	-1	6.2	1054
02b Uw 2.8 / g 0.78 / shutte	1	359	9.88	440	50	19	0.2	1874	8	0.7	1373	-6	4.9	881
03b Uw 1.7 / g 0.65 / shutte	1	380	10.18	466	50	7	0.2	1355	2	0.6	1093	-6	4.0	856
04b Uw 1.3 / g 0.6 / shutter	1	381	10.19	468	50	5	0.2	1210	0	0.6	1014	-6.3	3.7	846
05b Uw 1 / g 0.55 / shutter	1	423	10.76	519	50	2.4	0.1	1186	-0.9	0.5	1039	-6.1	3.4	923
06b Uw 0.8 / g 0.6 / shutter	1	528	12.19	648	50	-0.4	0.2	1243	-2.9	0.6	1141	-7.2	3.6	1075
07b Uw 1 / g 0.58 / shutter	1	495	11.74	607	50	1.9	0.2	1298	-1.4	0.6	1154	-6.5	3.5	1044
08b Uw 0.6 / g 0.47 / shutte	1	635	13.64	778	50	-0.2	0.1	1458	-2.2	0.5	1376	-5.6	3.0	1328
09b Uw 2.8 / g 0.35 / shutte	1	413	10.62	506	50	26	0.1	2351	15	0.4	1789	1	3.1	1219
10b Uw 1.3 / g 0.35 / shutte	1	424	10.77	520	50	9	0.1	1508	4	0.4	1276	-3	2.6	1063
11b Uw 0.8 / g 0.35 / shutte	1	581	12.91	712	50	4	0.1	1560	1	0.4	1422	-3	2.5	1311
lowest LCC without shutters						06a	09a	05a	06a	09a	04a	06a	11a	04a
lowest LCC with shutters						06b	09b	05b	06b	09b	04b	06b	11b	04b
lowest LCC with-without together						06b	09b	05a	06b	09b	04a	06b	11b	04a

The table shows that in the **North climate condition** the cooling costs are not significant and the least life cycle cost (calculated as combined heating, cooling and purchase costs) is achieved by option 5a_Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Improved frame (wood, PVC, Metal). The options without shutter are generally somewhat less costly than options with shutters (in other words, there is little risk of overheating and the additional costs of shutters do not pay back themselves). **The other options 4a/6a are within 10% deviation from LLCC=4a.**

In the Central climate condition, the least life cost is achieved by 4a_Double IGU Low-e argon. Again, options without shutters are somewhat less costly, as the cooling costs are still relatively low. Window 5a (triple glazing) is almost exactly the same life cycle costs. **This example shows that windows with different U_W values and g-values may perform quite identical** in this climate condition**.**

In the South climate condition, cooling costs may exceed heating costs for all window types. The least life cycle cost window option is a shutter less window 4a_ Double IGU Low-e argon, but the difference with window type 3a (double glazing with Low E) and 5a (triple glazing) also if equipped with shutters is small. **Together with type 10a with solar control glazing and type 4b (with shutters) these types show very low LCC values (<10% deviation from LLCC=4a).**

All above conclusions must be interpreted in the light of the underlying boundary conditions, which means that depending on the site/location and the specific building in which the window is to be installed, the boundary conditions may be selected differently and the conclusions may change. Overall. once can conclude that certain windows types with different U- and g-values (e.g. type 3, 4 and 5) show very similar results.

The table below shows the shares of Purchase, energy and maintenance in the overall life cycle costs. Clearly visible the share of energy drops from more than 50% for lower performing windows to a negative value (up to minus 14% in Southern climate condition) for higher performing windows.

Table 11 Shares of purchase, energy and maintenance in total LCC

	North			Central			South		
	Purchase	Energy	Maintenance	Purchase	Energy	Maintenance	Purchase	Energy	Maintenance
01a Uw 5.8 / g 0.85	5%	86%	9%	8%	78%	15%	15%	56%	29%
02a Uw 2.8 / g 0.78	16%	62%	22%	22%	46%	32%	30%	27%	43%
03a Uw 1.7 / g 0.65	26%	39%	35%	34%	21%	46%	37%	14%	49%
04a Uw 1.3 / g 0.6	31%	28%	41%	38%	11%	51%	38%	10%	52%
05a Uw 1 / g 0.55	37%	17%	46%	43%	3%	54%	42%	6%	52%
06a Uw 0.8 / g 0.6	48%	2%	51%	53%	-9%	56%	47%	2%	50%
07a Uw 1 / g 0.58	41%	13%	46%	47%	0%	52%	45%	5%	50%
08a Uw 0.6 / g 0.47	50%	1%	48%	54%	-5%	51%	50%	2%	48%
09a Uw 2.8 / g 0.35	15%	65%	19%	21%	52%	27%	32%	29%	40%
10a Uw 1.3 / g 0.35	28%	38%	34%	34%	24%	42%	39%	12%	48%
11a Uw 0.8 / g 0.35	41%	17%	42%	46%	7%	46%	47%	5%	48%
01b Uw 5.8 / g 0.85 / shutter	10%	77%	13%	15%	65%	19%	32%	26%	42%
02b Uw 2.8 / g 0.78 / shutter	23%	50%	26%	32%	32%	36%	50%	-6%	56%
03b Uw 1.7 / g 0.65 / shutter	34%	28%	38%	43%	11%	47%	55%	-14%	59%
04b Uw 1.3 / g 0.6 / shutter	39%	19%	42%	46%	4%	50%	55%	-16%	60%
05b Uw 1 / g 0.55 / shutter	44%	11%	45%	50%	-2%	52%	56%	-15%	58%
06b Uw 0.8 / g 0.6 / shutter	52%	-1%	49%	57%	-10%	53%	60%	-17%	57%
07b Uw 1 / g 0.58 / shutter	47%	8%	45%	53%	-3%	51%	58%	-14%	56%
08b Uw 0.6 / g 0.47 / shutter	53%	0%	47%	57%	-6%	50%	59%	-10%	51%
09b Uw 2.8 / g 0.35 / shutter	22%	56%	23%	28%	42%	30%	42%	15%	44%
10b Uw 1.3 / g 0.35 / shutter	34%	30%	36%	41%	17%	42%	49%	0%	51%
11b Uw 0.8 / g 0.35 / shutter	46%	13%	41%	50%	5%	45%	54%	-3%	49%

The following sections show the sensitivity of the life cycle costing analysis when certain assumptions or conditions are changed.

6.2.1. SENSITIVITY TO WINDOW LIFE

The basic calculation assumes a window product life of 40 years. The additional calculations are performed for a window product life of 30 years (no pane change assumed in maintenance costs), and of 50 years (pane change assumed).

Note that all values are expressed for a total service life of 50 years which means that some 50/40 is 1.25 windows with a 40 year life will be used in that period of 50 years.

Table 12 Change in window life

	North			Central			South		
	40 yrs	30 yrs	50 yrs	40 yrs	30 yrs	50 yrs	40 yrs	30 yrs	50 yrs
01a Uw 5.8 / g 0.85	3771	3715	3736	2426	2370	2391	1242	1186	1207
02a Uw 2.8 / g 0.78	1825	1740	1772	1281	1197	1229	957	873	905
03a Uw 1.7 / g 0.65	1203	1110	1145	929	837	871	857	765	799
04a Uw 1.3 / g 0.6	1029	936	971	829	736	771	821	728	763
05a Uw 1 / g 0.55	986	879	919	840	733	773	873	766	806
06a Uw 0.8 / g 0.6	1035	889	944	939	793	848	1044	898	953
07a Uw 1 / g 0.58	1098	965	1015	957	824	874	1007	873	923
08a Uw 0.6 / g 0.47	1239	1055	1124	1162	978	1047	1243	1059	1128
09a Uw 2.8 / g 0.35	2291	2187	2226	1676	1572	1611	1120	1016	1055
10a Uw 1.3 / g 0.35	1320	1212	1253	1079	971	1011	936	828	869
11a Uw 0.8 / g 0.35	1346	1182	1243	1208	1043	1105	1179	1014	1076
01b Uw 5.8 / g 0.85 / shut	3440	3339	3377	2266	2165	2202	1054	953	991
02b Uw 2.8 / g 0.78 / shut	1874	1744	1793	1373	1244	1292	881	752	800
03b Uw 1.7 / g 0.65 / shut	1355	1217	1269	1093	956	1007	856	718	770
04b Uw 1.3 / g 0.6 / shutt	1210	1072	1124	1014	876	927	846	708	760
05b Uw 1 / g 0.55 / shutte	1186	1033	1091	1039	886	943	923	770	827
06b Uw 0.8 / g 0.6 / shutt	1243	1052	1124	1141	950	1021	1075	884	956
07b Uw 1 / g 0.58 / shutte	1298	1119	1186	1154	975	1042	1044	865	932
08b Uw 0.6 / g 0.47 / shut	1458	1229	1315	1376	1146	1232	1328	1099	1185
09b Uw 2.8 / g 0.35 / shut	2351	2202	2258	1789	1639	1695	1219	1070	1126
10b Uw 1.3 / g 0.35 / shut	1508	1355	1412	1276	1123	1180	1063	910	967
11b Uw 0.8 / g 0.35 / shut	1560	1351	1429	1422	1212	1291	1311	1101	1180
lowest LCC without shutte	05a	05a	05a	04a	05a	04a	04a	04a	04a
lowest LCC with shutters	05b	05b	05b	04b	04b	04b	04b	04b	04b
lowest LCC with-without t	05a	05a	05a	04a	05a	04a	04a	04b	04b

The assessment shows that the least life cycle cost point is relatively unaffected by changes in product life. Note that the 30 years life values do not assume glazing replacement which can make a big difference for some window types.

Overall it appears that lengthening of product life is favourable for the LCC of more costly window types, as to be expected.

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6.2.2. SENSITIVITY TO WINDOW PURCHASE COSTS

The scarce information as regards windows purchase prices, shows that window prices vary considerably. A mark-up of 0.75 and 1.25 has been applied to assess the effects.

Table 13 Change in purchase price

				North			Central			South		
	PP=1	PP=0.75	PP=1.25	PP=1	PP=0.75	PP=1.25	PP=1	PP=0.75	PP=1.25	PP=1	PP=0.75	PP=1.25
1a Uw 5.8 / g 0.85	154	116	193	3771	3697	3844	2426	2352	2500	1242	1169	1316
2a Uw 2.8 / g 0.78	234	175	292	1825	1713	1936	1281	1170	1393	957	846	1069
3a Uw 1.7 / g 0.65	255	192	319	1203	1081	1324	929	807	1051	857	735	979
4a Uw 1.3 / g 0.6	256	192	321	1029	906	1151	829	707	951	821	699	943
5a Uw 1 / g 0.55	298	224	373	986	844	1129	840	698	982	873	731	1015
6a Uw 0.8 / g 0.6	403	302	504	1035	843	1227	939	747	1131	1044	852	1236
7a Uw 1 / g 0.58	370	278	463	1098	922	1275	957	781	1134	1007	830	1183
8a Uw 0.6 / g 0.47	510	382	637	1239	996	1482	1162	919	1405	1243	1000	1486
9a Uw 2.8 / g 0.35	288	216	360	2291	2154	2429	1676	1539	1813	1120	983	1258
10a Uw 1.3 / g 0.35	299	224	374	1320	1178	1463	1079	937	1221	936	794	1079
11a Uw 0.8 / g 0.35	456	342	570	1346	1129	1564	1208	991	1425	1179	961	1396
1b Uw 5.8 / g 0.85 / shutter	279	241	318	3440	3366	3513	2266	2192	2339	1054	981	1128
2b Uw 2.8 / g 0.78 / shutter	359	300	417	1874	1763	1985	1373	1262	1485	881	770	993
3b Uw 1.7 / g 0.65 / shutter	380	317	444	1355	1233	1477	1093	971	1215	856	734	977
4b Uw 1.3 / g 0.6 / shutter	381	317	446	1210	1088	1332	1014	891	1136	846	724	968
5b Uw 1 / g 0.55 / shutter	423	349	498	1186	1044	1328	1039	897	1181	923	780	1065
6b Uw 0.8 / g 0.6 / shutter	528	427	629	1243	1051	1435	1141	949	1333	1075	883	1267
7b Uw 1 / g 0.58 / shutter	495	403	588	1298	1121	1474	1154	978	1331	1044	867	1220
8b Uw 0.6 / g 0.47 / shutter	635	507	762	1458	1215	1701	1376	1133	1619	1328	1085	1572
9b Uw 2.8 / g 0.35 / shutter	413	341	485	2351	2214	2488	1789	1651	1926	1219	1082	1356
10b Uw 1.3 / g 0.35 / shutte	424	349	499	1508	1365	1650	1276	1133	1418	1063	920	1205
11b Uw 0.8 / g 0.35 / shutte	581	467	695	1560	1343	1778	1422	1205	1639	1311	1094	1529
lowest LCC without shutters				5a	6a	5a	4a	5a	4a	4a	4a	4a
lowest LCC with shutters				5b	5b	5b	4b	4b	4b	4b	4b	4b
lowest LCC with-without together				5a	6a	5a	4a	5a	4a	4a	4a	4a

The analysis shows that the least life cycle cost point is relatively untouched. In some conditions a very small shift can be observed .

6.2.3. Sensitivity to shutter costs

A change is shutter costs (only applicable to window 'b' types, with shutters) results in an increase of LCC of windows with shutters. Variants of shutter costs of 75 and 200 euro (additional to the basic purchase costs) has been assumed.

Table 14 Change in shutter costs

				North			Central			South		
	shutter= 125	shutter= 75	shutter= 200	shutter= 125	shutter= 75	shutter= 200	shutter= 125	shutter= 75	shutter= 200	shutter= 125	shutter= 75	shutter= 200
1a Uw 5.8 / g 0.85	154	154	154	3771	3771	3771	2426	2426	2426	1242	1242	1242
2a Uw 2.8 / g 0.78	234	234	234	1825	1825	1825	1281	1281	1281	957	957	957
3a Uw 1.7 / g 0.65	255	255	255	1203	1203	1203	929	929	929	857	857	857
4a Uw 1.3 / g 0.6	256	256	256	1029	1029	1029	829	829	829	821	821	821
5a Uw 1 / g 0.55	298	298	298	986	986	986	840	840	840	873	873	873
6a Uw 0.8 / g 0.6	403	403	403	1035	1035	1035	939	939	939	1044	1044	1044
7a Uw 1 / g 0.58	370	370	370	1098	1098	1098	957	957	957	1007	1007	1007
8a Uw 0.6 / g 0.47	510	510	510	1239	1239	1239	1162	1162	1162	1243	1243	1243
9a Uw 2.8 / g 0.35	288	288	288	2291	2291	2291	1676	1676	1676	1120	1120	1120
10a Uw 1.3 / g 0.35	299	299	299	1320	1320	1320	1079	1079	1079	936	936	936
11a Uw 0.8 / g 0.35	456	456	456	1346	1346	1346	1208	1208	1208	1179	1179	1179
1b Uw 5.8 / g 0.85 / shutter	279	229	354	3440	3345	3583	2266	2170	2409	1054	959	1197
2b Uw 2.8 / g 0.78 / shutter	359	309	434	1874	1779	2017	1373	1278	1516	881	786	1024
3b Uw 1.7 / g 0.65 / shutter	380	330	455	1355	1260	1498	1093	998	1236	856	760	999
4b Uw 1.3 / g 0.6 / shutter	381	331	456	1210	1115	1353	1014	918	1157	846	751	989
5b Uw 1 / g 0.55 / shutter	423	373	498	1186	1091	1329	1039	943	1182	923	827	1066
6b Uw 0.8 / g 0.6 / shutter	528	478	603	1243	1148	1386	1141	1046	1284	1075	980	1218
7b Uw 1 / g 0.58 / shutter	495	445	570	1298	1202	1441	1154	1059	1297	1044	948	1187
8b Uw 0.6 / g 0.47 / shutter	635	585	710	1458	1363	1601	1376	1280	1519	1328	1233	1471
9b Uw 2.8 / g 0.35 / shutter	413	363	488	2351	2256	2494	1789	1693	1932	1219	1124	1362
10b Uw 1.3 / g 0.35 / shutte	424	374	499	1508	1412	1651	1276	1180	1419	1063	968	1206
11b Uw 0.8 / g 0.35 / shutte	581	531	656	1560	1465	1704	1422	1327	1565	1311	1216	1454
			lowest LCC without shutte	5a	5a	5a	4a	4a	4a	4a	4a	4a
			lowest LCC with shutters	5b	5b	5b	4b	4b	4b	4b	4b	4b
			lowest LCC with-without t	5a	5a	5a	4a	4a	4a	4a	4b	4a

The windows in the South conditions are most affected by a change in shutter costs. The effect on LCC for lower shutter costs is that the LCC in the South conditions shifts towards windows with shutters. An increase in shutter costs has the opposite effect.

6.2.4. SENSITIVITY TO HEATING EFFICIENCY

A change is heating efficiency is modelled for heating efficiencies of 85% and 125% (these are to be understood as annual efficiencies). The average efficiency was set at 59% annual efficiency (similar to TASK 3 and TASK 7 Scenario's).

Table 15 Change in heating efficiency

				North			Central			South		
	ref. (=50%)	Heating eff.= 85%	Heating eff.= 125%	ref. (=50%)	Heating eff.= 85%	Heating eff.= 125%	ref. (=50%)	Heating eff.= 85%	Heating eff.= 125%	ref. (=50%)	Heating eff.= 85%	Heating eff.= 125%
1a Uw 5.8 / g 0.85	154	154	154	3771	2776	2131	2426	1864	1501	1242	1216	1199
2a Uw 2.8 / g 0.78	234	234	234	1825	1481	1259	1281	1121	1017	957	1038	1090
3a Uw 1.7 / g 0.65	255	255	255	1203	1064	975	929	887	860	857	951	1012
4a Uw 1.3 / g 0.6	256	256	256	1029	945	890	829	818	810	821	916	977
5a Uw 1 / g 0.55	298	298	298	986	940	910	840	849	854	873	966	1026
6a Uw 0.8 / g 0.6	403	403	403	1035	1036	1037	939	980	1007	1044	1155	1226
7a Uw 1 / g 0.58	370	370	370	1098	1060	1035	957	973	983	1007	1106	1171
8a Uw 0.6 / g 0.47	510	510	510	1239	1239	1238	1162	1194	1214	1243	1329	1385
9a Uw 2.8 / g 0.35	288	288	288	2291	1831	1533	1676	1413	1243	1120	1100	1087
10a Uw 1.3 / g 0.35	299	299	299	1320	1168	1070	1079	1008	962	936	973	996
11a Uw 0.8 / g 0.35	456	456	456	1346	1279	1236	1208	1190	1178	1179	1231	1264
1b Uw 5.8 / g 0.85 / shutter	279	279	279	3440	2616	2083	2266	1817	1526	1054	1066	1073
2b Uw 2.8 / g 0.78 / shutter	359	359	359	1874	1584	1397	1373	1248	1167	881	974	1033
3b Uw 1.7 / g 0.65 / shutter	380	380	380	1355	1239	1165	1093	1066	1049	856	955	1019
4b Uw 1.3 / g 0.6 / shutter	381	381	381	1210	1140	1095	1014	1011	1010	846	944	1008
5b Uw 1 / g 0.55 / shutter	423	423	423	1186	1148	1124	1039	1053	1062	923	1017	1078
6b Uw 0.8 / g 0.6 / shutter	528	528	528	1243	1250	1254	1141	1186	1215	1075	1187	1259
7b Uw 1 / g 0.58 / shutter	495	495	495	1298	1268	1249	1154	1176	1189	1044	1145	1211
8b Uw 0.6 / g 0.47 / shutter	635	635	635	1458	1461	1463	1376	1409	1431	1328	1416	1472
9b Uw 2.8 / g 0.35 / shutter	413	413	413	2351	1944	1681	1789	1561	1414	1219	1211	1205
10b Uw 1.3 / g 0.35 / shutte	424	424	424	1508	1370	1280	1276	1214	1174	1063	1102	1128
11b Uw 0.8 / g 0.35 / shutte	581	581	581	1560	1499	1459	1422	1408	1399	1311	1365	1399
lowest LCC without shutters				5a	5a	4a	4a	4a	4a	4a	4a	4a
lowest LCC with shutters				5b	4b	4b	4b	4b	4b	4b	4b	4b
lowest LCC with-without together				5a	5a	4a	4a	4a	4a	4a	4a	4a

The shift in LLCC is more visible in the Northern climate condition: Less thermally performing windows are becoming more attractive if heating efficiency goes up (or heating costs go down). For the Southern the effect is mainly visible for high performing windows types with shutters. Apparently the extra shutter costs, makes these windows less attractive, as the reduced heating costs cannot recuperate the price increase related to thermal improvement (heating period).

6.2.5. SENSITIVITY TO COOLING COSTS/EFFICIENCY

As stated in the paragraph explaining the assumptions behind the LCC calculations, it may be that the relevance of cooling costs in the LCC are overestimated, as certain buildings simply do not have cooling equipment, allowing higher internal temperatures (change in boundary conditions!), leading to zero cooling costs.

It may also be that the efficiency of the cooling system (reference set at 311%) is actually lower, indicatively 140%, as techniques may vary (and also to show effects of higher cooling costs).

In order to assess the effects of reduced or zero cooling costs, an additional calculation assuming 0 euro/kWh cooling costs was introduced.

Table 16 Change in cooling costs/efficiency

				North			Central			South		
	ref.	Cooling eff.= 1.4	Cooling costs = 0 euro	ref.	Cooling eff.= 1.4	Cooling costs = 0 euro	ref.	Cooling eff.= 1.4	Cooling costs = 0 euro	ref.	Cooling eff.= 1.4	Cooling costs = 0 euro
1a Uw 5.8 / g 0.85	154	154	154	3771	3799	3748	2426	2516	2352	1242	1991	629
2a Uw 2.8 / g 0.78	234	234	234	1825	1854	1801	1281	1365	1213	957	1594	436
3a Uw 1.7 / g 0.65	255	255	255	1203	1228	1182	929	999	872	857	1374	433
4a Uw 1.3 / g 0.6	256	256	256	1029	1052	1009	829	894	776	821	1294	433
5a Uw 1 / g 0.55	298	298	298	986	1008	968	840	900	792	873	1305	520
6a Uw 0.8 / g 0.6	403	403	403	1035	1059	1015	939	1004	885	1044	1510	663
7a Uw 1 / g 0.58	370	370	370	1098	1122	1079	957	1020	906	1007	1460	635
8a Uw 0.6 / g 0.47	510	510	510	1239	1258	1224	1162	1213	1120	1243	1608	944
9a Uw 2.8 / g 0.35	288	288	288	2291	2303	2282	1676	1713	1646	1120	1433	864
10a Uw 1.3 / g 0.35	299	299	299	1320	1334	1310	1079	1117	1048	936	1222	702
11a Uw 0.8 / g 0.35	456	456	456	1346	1360	1335	1208	1246	1177	1179	1456	951
1b Uw 5.8 / g 0.85 / shutter	279	279	279	3440	3446	3435	2266	2311	2228	1054	1431	746
2b Uw 2.8 / g 0.78 / shutter	359	359	359	1874	1884	1866	1373	1417	1338	881	1180	637
3b Uw 1.7 / g 0.65 / shutter	380	380	380	1355	1364	1347	1093	1131	1062	856	1100	656
4b Uw 1.3 / g 0.6 / shutter	381	381	381	1210	1219	1202	1014	1049	985	846	1071	662
5b Uw 1 / g 0.55 / shutter	423	423	423	1186	1195	1179	1039	1072	1012	923	1131	752
6b Uw 0.8 / g 0.6 / shutter	528	528	528	1243	1253	1235	1141	1176	1112	1075	1293	897
7b Uw 1 / g 0.58 / shutter	495	495	495	1298	1307	1290	1154	1189	1126	1044	1259	867
8b Uw 0.6 / g 0.47 / shutter	635	635	635	1458	1466	1451	1376	1405	1352	1328	1510	1180
9b Uw 2.8 / g 0.35 / shutter	413	413	413	2351	2355	2348	1789	1811	1770	1219	1408	1064
10b Uw 1.3 / g 0.35 / shutte	424	424	424	1508	1514	1503	1276	1299	1257	1063	1224	931
11b Uw 0.8 / g 0.35 / shutte	581	581	581	1560	1567	1555	1422	1445	1403	1311	1465	1185
lowest LCC without shutters				5a	5a	5a	4a	4a	4a	4a	10a	4a
lowest LCC with shutters				5b	5b	5b	4b	4b	4b	4b	4b	2b
lowest LCC with-without together				5a	5a	5a	4a	4a	4a	4a	4b	4a

The results show that windows allowing higher solar heat gains (type 2a, 3a, without shutters) are becoming more attractive, but the differences remain limited, also for the Southern climate condition. Reduction of cooling efficiency (efficiency at 140%) has the opposite effect, and decreases costs for options with shutters..

6.2.6. Sensitivity to change in discount & escalation rate

The life cycle costing analysis assumes a standard discount (reduces future costs) rate of 4% and an escalation rate (increases future costs) of again 4%. As both rates cancel each other out, the present worth factor is similar to the view period to which the cost calculation applies (PWF is view period, is 50 yrs.).

Two variations have been assessed: the first has an escalation rate of 2% (half of discount rate, PWF is 32 yrs.) and lowers the relevance of energy costs of the viewing period. The second variation has a discount rate of 2% (half of escalation rate 4%) and lowers the future purchase costs (or raises the energy costs, PWF is 85 yrs.). The effects on LCC are shown below.

Table 17 Change in discount/escalation rate

				North			Central			South		
	PWF @ d=e	PWF @ d=4%, e=2%	PWF @ d=2%, e=4%	PWF @ d=e	PWF @ d=4%, e=2%	PWF @ d=2%, e=4%	PWF @ d=e	PWF @ d=4%, e=2%	PWF @ d=2%, e=4%	PWF @ d=e	PWF @ d=4%, e=2%	PWF @ d=2%, e=4%
1a Uw 5.8 / g 0.85	50	32	85	3771	2459	6299	2426	1607	4005	1242	856	1986
2a Uw 2.8 / g 0.78	50	32	85	1825	1261	2911	1281	917	1984	957	712	1431
3a Uw 1.7 / g 0.65	50	32	85	1203	877	1831	929	703	1364	857	658	1241
4a Uw 1.3 / g 0.6	50	32	85	1029	767	1533	829	641	1192	821	635	1178
5a Uw 1 / g 0.55	50	32	85	986	759	1425	840	666	1176	873	687	1232
6a Uw 0.8 / g 0.6	50	32	85	1035	837	1417	939	776	1252	1044	843	1432
7a Uw 1 / g 0.58	50	32	85	1098	862	1553	957	773	1313	1007	804	1397
8a Uw 0.6 / g 0.47	50	32	85	1239	1014	1673	1162	965	1541	1243	1017	1679
9a Uw 2.8 / g 0.35	50	32	85	2291	1581	3660	1676	1191	2610	1120	839	1662
10a Uw 1.3 / g 0.35	50	32	85	1320	971	1994	1079	818	1582	936	727	1338
11a Uw 0.8 / g 0.35	50	32	85	1346	1058	1903	1208	970	1666	1179	952	1616
1b Uw 5.8 / g 0.85 / shutter	50	32	85	3440	2305	5627	2266	1561	3623	1054	793	1557
2b Uw 2.8 / g 0.78 / shutter	50	32	85	1874	1349	2887	1373	1031	2033	881	719	1193
3b Uw 1.7 / g 0.65 / shutter	50	32	85	1355	1029	1982	1093	863	1535	856	713	1130
4b Uw 1.3 / g 0.6 / shutter	50	32	85	1210	938	1734	1014	814	1399	846	707	1113
5b Uw 1 / g 0.55 / shutter	50	32	85	1186	942	1657	1039	848	1406	923	775	1208
6b Uw 0.8 / g 0.6 / shutter	50	32	85	1243	1025	1664	1141	960	1489	1075	918	1377
7b Uw 1 / g 0.58 / shutter	50	32	85	1298	1045	1785	1154	954	1541	1044	884	1352
8b Uw 0.6 / g 0.47 / shutter	50	32	85	1458	1209	1938	1376	1157	1797	1328	1127	1717
9b Uw 2.8 / g 0.35 / shutter	50	32	85	2351	1675	3653	1789	1319	2694	1219	958	1722
10b Uw 1.3 / g 0.35 / shutte	50	32	85	1508	1146	2205	1276	999	1809	1063	864	1446
11b Uw 0.8 / g 0.35 / shutte	50	32	85	1560	1250	2160	1422	1162	1924	1311	1092	1734
lowest LCC without shutters				5a	5a	6a	4a	4a	5a	4a	4a	4a
lowest LCC with shutters				5b	4b	5b	4b	4b	4b	4b	4b	4b
lowest LCC with-without together				5a	5a	6a	4a	4a	5a	4a	4a	4b

As could be expected the lower escalation rate (lower energy prices) makes less performing windows more attractive, and vice versa. The differences in relative ranking are however not very significant. The lowest LCC is consistent for all.

6.2.7. SENSITIVITY TO WINDOW ORIENTATION

Several stakeholders have asked for consideration of the window orientation in the life cycle cost analysis. Based on the analysis presented in TASK 7, the ABC/XYZ values for 4 additional orientations were established.

The energy performance was established using the ABC/XYZ values as presented in Table 3.

The results of the calculations are shown below. The total life cycle costs (shown in main table) are the summation of heating and cooling costs (also shown in separate tables) and maintenance costs / glazing repair costs over the total view period of 50 yrs. and purchase costs. Contrary to the previous analysis this analysis does not include solar control glazing options (low g-values) combined with solar shading[11].

[11] The combination of solar control glazing (low g-values) and solar shading (shutters) was considered in the preceding analysis in order to have a complete overview of possible costs, but the combination may not be realistic, which is why it was 'greyed out' in the overview of sensitivity to orientation.

Table 18 Annual heating costs per orientation (façade windows)

	North					Central					South				
window types	unif.	N	E	S	W	unif.	N	E	S	W	unif.	N	E	S	W
01a Uw 5.8 / g 0.85	64	82	66	42	65	36	49	39	20	37	2	13	3	-10	2
02a Uw 2.8 / g 0.78	22	34	23	8	23	10	19	12	0	11	-5	3	-5	-14	-5
03a Uw 1.7 / g 0.65	9	17	10	-1	9	3	9	4	-5	3	-6	0	-6	-13	-6
04a Uw 1.3 / g 0.6	5	13	6	-3	6	1	6	2	-6	1	-6	-1	-6	-12	-6
05a Uw 1 / g 0.55	3	9	4	-5	3	-1	4	0	-7	0	-6	-1	-6	-11	-6
06a Uw 0.8 / g 0.6	0	6	1	-8	0	-3	2	-2	-9	-2	-7	-2	-7	-13	-7
07a Uw 1 / g 0.58	2	9	3	-5	3	-1	4	0	-7	-1	-6	-1	-6	-12	-6
08a Uw 0.6 / g 0.47	0	5	1	-6	0	-2	2	-1	-7	-2	-6	-1	-5	-10	-5
09a Uw 2.8 / g 0.35	30	38	30	20	30	17	23	18	10	17	1	6	2	-4	2
10a Uw 1.3 / g 0.35	10	15	10	4	10	5	8	5	0	5	-2	1	-2	-6	-2
11a Uw 0.8 / g 0.35	4	9	5	-1	5	1	4	2	-3	1	-3	0	-3	-7	-3
01b Uw 5.8 / g 0.85 / shutter	53	70	55	33	54	29	41	31	14	30	-1	10	0	-11	0
02b Uw 2.8 / g 0.78 / shutter	19	30	20	5	19	8	16	10	-2	9	-6	2	-5	-14	-5
03b Uw 1.7 / g 0.65 / shutter	7	16	8	-2	8	2	8	3	-6	2	-6	0	-6	-13	-6
04b Uw 1.3 / g 0.6 / shutter	5	12	5	-4	5	0	5	1	-7	0	-6	-1	-6	-12	-6
05b Uw 1 / g 0.55 / shutter	2	9	3	-5	3	-1	4	0	-7	-1	-6	-1	-6	-11	-6
06b Uw 0.8 / g 0.6 / shutter	0	6	0	-8	0	-3	2	-2	-9	-3	-7	-2	-7	-13	-7
07b Uw 1 / g 0.58 / shutter	2	8	3	-6	2	-1	3	0	-8	-1	-7	-1	-6	-12	-6
08b Uw 0.6 / g 0.47 / shutter	0	5	0	-6	0	-2	2	-1	-7	-2	-6	-2	-5	-10	-5
09b Uw 2.8 / g 0.35 / shutter	26	38	30	20	30	15	23	18	10	17	1	6	2	-4	2
10b Uw 1.3 / g 0.35 / shutter	9	15	10	4	10	4	8	5	0	5	-3	1	-2	-6	-2
11b Uw 0.8 / g 0.35 / shutter	4	9	5	-1	5	1	4	2	-3	1	-3	0	-3	-7	-3

Table 19 Annual cooling costs per orientation (façade windows)

	North					Central					South				
window types	unif.	N	E	S	W	unif.	N	E	S	W	unif.	N	E	S	W
01a Uw 5.8 / g 0.85	0.5	0.2	0.6	0.6	0.6	1.5	0.9	1.8	1.5	1.6	12.3	7.6	13.5	11.2	13.6
02a Uw 2.8 / g 0.78	0.5	0.2	0.6	0.6	0.6	1.4	0.8	1.7	1.4	1.5	10.4	6.0	12.1	10.0	12.1
03a Uw 1.7 / g 0.65	0.4	0.2	0.5	0.5	0.5	1.1	0.7	1.4	1.2	1.3	8.5	4.8	10.0	8.2	10.0
04a Uw 1.3 / g 0.6	0.4	0.1	0.5	0.5	0.4	1.1	0.6	1.3	1.1	1.2	7.8	4.3	9.2	7.6	9.2
05a Uw 1 / g 0.55	0.4	0.1	0.4	0.4	0.4	1.0	0.6	1.2	1.0	1.1	7.1	3.9	8.4	6.9	8.5
06a Uw 0.8 / g 0.6	0.4	0.1	0.5	0.5	0.4	1.1	0.6	1.3	1.1	1.2	7.6	4.2	9.2	7.5	9.2
07a Uw 1 / g 0.58	0.4	0.1	0.5	0.5	0.4	1.0	0.6	1.3	1.1	1.1	7.4	4.1	8.9	7.3	8.9
08a Uw 0.6 / g 0.47	0.3	0.1	0.4	0.4	0.3	0.8	0.5	1.0	0.9	0.9	6.0	3.3	7.2	5.9	7.2
09a Uw 2.8 / g 0.35	0.2	0.1	0.2	0.2	0.2	0.6	0.4	0.7	0.6	0.7	5.1	3.2	5.6	4.6	5.6
10a Uw 1.3 / g 0.35	0.2	0.1	0.3	0.3	0.2	0.6	0.4	0.8	0.6	0.7	4.7	2.7	5.4	4.5	5.4
11a Uw 0.8 / g 0.35	0.2	0.1	0.3	0.3	0.3	0.6	0.4	0.8	0.6	0.7	4.5	2.5	5.4	4.4	5.4
01b Uw 5.8 / g 0.85 / shut	0.1	0.2	0.1	0.1	0.1	0.8	0.9	0.8	0.6	0.7	6.2	7.6	4.8	4.3	4.8
02b Uw 2.8 / g 0.78 / shut	0.2	0.2	0.2	0.2	0.2	0.7	0.8	0.8	0.6	0.7	4.9	6.0	4.2	3.7	4.2
03b Uw 1.7 / g 0.65 / shut	0.2	0.2	0.2	0.2	0.2	0.6	0.7	0.7	0.5	0.6	4.0	4.8	3.6	3.2	3.6
04b Uw 1.3 / g 0.6 / shutt	0.2	0.1	0.2	0.1	0.1	0.6	0.6	0.7	0.5	0.5	3.7	4.3	3.4	3.0	3.4
05b Uw 1 / g 0.55 / shutte	0.1	0.1	0.2	0.1	0.1	0.5	0.6	0.6	0.5	0.5	3.4	3.9	3.2	2.8	3.2
06b Uw 0.8 / g 0.6 / shutt	0.2	0.1	0.2	0.2	0.2	0.6	0.6	0.7	0.5	0.5	3.6	4.2	3.3	3.0	3.3
07b Uw 1 / g 0.58 / shutte	0.2	0.1	0.2	0.2	0.1	0.6	0.6	0.6	0.5	0.5	3.5	4.1	3.3	2.9	3.3
08b Uw 0.6 / g 0.47 / shut	0.1	0.1	0.2	0.1	0.1	0.5	0.5	0.5	0.4	0.5	3.0	3.3	2.9	2.5	2.9
09b Uw 2.8 / g 0.35 / shut	0.1	0.1	0.2	0.2	0.2	0.4	0.4	0.7	0.6	0.7	3.1	3.2	5.6	4.6	5.6
10b Uw 1.3 / g 0.35 / shut	0.1	0.1	0.3	0.3	0.2	0.4	0.4	0.8	0.6	0.7	2.6	2.7	5.4	4.5	5.4
11b Uw 0.8 / g 0.35 / shut	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.8	0.6	0.7	2.5	2.5	5.4	4.4	5.4

Table 20 Total life cycle costs per orientation (façade windows)

	North					Central					South				
window types	unif.	N	E	S	W	unif.	N	E	S	W	unif.	N	E	S	W
01a Uw 5.8 / g 0.85	3771	4674	3870	2677	3830	2426	3054	2565	1611	2481	1242	1563	1346	621	1338
02a Uw 2.8 / g 0.78	1825	2389	1894	1136	1866	1281	1675	1382	753	1317	957	1141	1069	509	1067
03a Uw 1.7 / g 0.65	1203	1604	1255	711	1233	929	1210	1006	546	955	857	981	954	515	954
04a Uw 1.3 / g 0.6	1029	1379	1075	599	1056	829	1075	898	492	852	821	927	912	514	912
05a Uw 1 / g 0.55	986	1293	1028	609	1011	840	1056	902	543	861	873	964	958	599	958
06a Uw 0.8 / g 0.6	1035	1346	1078	652	1061	939	1157	1004	634	960	1044	1133	1138	756	1139
07a Uw 1 / g 0.58	1098	1417	1142	707	1124	957	1181	1022	648	979	1007	1101	1096	719	1096
08a Uw 0.6 / g 0.47	1239	1483	1273	939	1259	1162	1334	1213	923	1178	1243	1313	1316	1017	1317
09a Uw 2.8 / g 0.35	2291	2687	2334	1813	2317	1676	1951	1736	1321	1700	1120	1262	1162	854	1158
10a Uw 1.3 / g 0.35	1320	1573	1351	1013	1339	1079	1255	1124	843	1095	936	1018	986	735	985
11a Uw 0.8 / g 0.35	1346	1559	1374	1086	1363	1208	1357	1249	1004	1222	1179	1244	1231	996	1231
01b Uw 5.8 / g 0.85 / shutter	3440	4278	3524	2431	3487	2266	2872	2382	1511	2305	1054	1643	1024	428	1014
02b Uw 2.8 / g 0.78 / shutter	1874	2428	1935	1209	1909	1373	1782	1459	859	1398	881	1329	873	408	868
03b Uw 1.7 / g 0.65 / shutter	1355	1758	1402	870	1382	1093	1393	1159	712	1111	856	1198	856	489	854
04b Uw 1.3 / g 0.6 / shutter	1210	1565	1252	783	1234	1014	1279	1073	676	1029	846	1152	849	516	847
05b Uw 1 / g 0.55 / shutter	1186	1500	1224	810	1208	1039	1273	1092	740	1052	923	1195	928	627	927
06b Uw 0.8 / g 0.6 / shutter	1243	1563	1283	859	1266	1141	1381	1197	833	1154	1075	1366	1081	762	1080
07b Uw 1 / g 0.58 / shutter	1298	1623	1337	906	1320	1154	1398	1210	843	1168	1044	1331	1049	733	1047
08b Uw 0.6 / g 0.47 / shutter	1458	1709	1489	1156	1476	1376	1564	1420	1134	1387	1328	1548	1337	1084	1336
09b Uw 2.8 / g 0.35 / shutter	2351	2687	2334	1813	2317	1789	1951	1736	1321	1700	1219	1262	1162	854	1158
10b Uw 1.3 / g 0.35 / shutter	1508	1573	1351	1013	1339	1276	1255	1124	843	1095	1063	1018	986	735	985
11b Uw 0.8 / g 0.35 / shutter	1560	1559	1374	1086	1363	1422	1357	1249	1004	1222	1311	1244	1231	996	1231

The total LCC overview shows that in the Northern and Central climate conditions, the difference in performance of the same window type at different orientations is not so striking. The reason is that the U-value is a major influence to the overall performance and the cooling costs are moderate compared to heating costs.

In the Southern climate condition the balance between solar gains and thermal losses is much more sensitive to orientation. For windows facing North the benefit of a solar shading device is not present and a slight increase in U-value is observed (to achieve lowest LCC). For East and West oriented windows the lowest life cycle costs are achieved by windows with either a solar shading device or solar control glazing (type 10). This is because the cooling costs outweigh the heating costs and reduction of solar gain is preferred. This conclusion applies in the case there are indeed cooling costs. For the window facing south it is observed that the lowest LCC are achieved by windows with a low U-value and a high g-value, preferably combined with a shading device, but the difference is smaller than for east and west facing windows. For these windows the heating costs are quite influential and are achieved mainly by windows with a high g-value. As the difference between indoor and outdoor temperatures is much smaller in the Southern climate condition, the solar gains bring quite an important contribution to the (reduction of) heating costs.

6.3. LEAST LIFE CYCLE COSTS ROOF WINDOWS

The life cycle costs as calculated for roof windows are shown below. Note that for roof window 01 and 02 no purchase prices were given as these windows are no longer sold.

Table 21 Total life cycle costs for roof windows

						condition North			condition Central			condition South		
		Purchase costs, incl. installation, incl. VAT	Maintenance costs (euro/yr)	Purchase over functional unit, incl.VAT	PWF	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit	Annual heating costs (euro/yr)	Annual cooling costs (euro/yr)	Total costs over functional unit
Uw 6.6 / g 0.85	0	0	5	0	50	67	1.3	3650	34	3.8	2136	2	24.1	1560
Uw 3.2 / g 0.78	0	0	5	0	50	26	1.5	1613	11	3.8	986	-2	21.5	1235
Uw 1.7 / g 0.6	0	480	13.69	589	50	11	1.2	1861	3	3.0	1578	-2	16.4	1974
Uw 1.1 / g 0.5	0	708	19.09	868	50	6	1.0	2174	1	2.5	1998	-2	13.6	2389
Uw 0.9 / g 0.5	0	913	23.17	1119	50	4.1	1.1	2534	-0.1	2.5	2399	-2.5	13.5	2832
Uw 1.7 / g 0.35	0	578	15.45	708	50	13.6	0.7	2192	6.1	1.7	1867	-0.6	9.7	1935
Uw 6.6 / g 0.85 +shadi	1	125	7	153	50	55	0.1	3238	27	0.9	1886	1	6.4	847
Uw 3.2 / g 0.78 +shadi	1	125	7	153	50	22	0.3	1632	9	1.1	1009	-2	5.4	677
Uw 1.7 / g 0.6 +shading	1	605	15.95	742	50	9	0.4	2021	2	1.0	1710	-2	4.6	1643
Uw 1.1 / g 0.5 +shading	1	833	21.58	1021	50	5	0.4	2388	1	0.9	2181	-2	4.1	2191
Uw 0.9 / g 0.5 +shading	1	1038	25.66	1272	50	3.7	0.4	2757	-0.3	0.9	2587	-2.5	4.1	2635
Uw 1.7 / g 0.35 +shadi	1	703	17.71	861	50	12.3	0.2	2373	5.3	0.7	2047	-0.7	3.8	1899

6.3.1. Sensitivity to window purchase costs

The scarce information as regards windows purchase prices, shows that window prices vary considerably. A mark-up of 0.75 and 1.25 has been applied to assess the effects.

Table 22 Roof window life cycle cost sensitivity to purchase cost

	North			Central			South		
	PP=ref	PP*1.5	PP*0.75	PP=ref	PP*1.5	PP*0.75	PP=ref	PP*1.5	PP*0.75
Uw 6.6 / g 0.85	3650	3650.1	3650	2136	2136.5	2136	1560	1560.1	1560
Uw 3.2 / g 0.78	1613	1613.5	1613	986	985.8	986	1235	1234.6	1235
Uw 1.7 / g 0.6	1861	2373	1605	1578	2090	1322	1974	2485	1718
Uw 1.1 / g 0.5	2174	2960	1781	1998	2784	1605	2389	3175	1996
Uw 0.9 / g 0.5	2534	3547	2027	2399	3413	1892	2832	3846	2325
Uw 1.7 / g 0.35	2192	2807	1884	1867	2482	1560	1935	2550	1627
Uw 6.6 / g 0.85 +shad	3238	3238	3238	1886	1886	1886	847	847	847
Uw 3.2 / g 0.78 +shad	1632	1632	1632	1009	1009	1009	677	677	677
Uw 1.7 / g 0.6 +shadir	2021	2532	1765	1710	2221	1454	1643	2154	1387
Uw 1.1 / g 0.5 +shadir	2388	3174	1995	2181	2967	1788	2191	2977	1798
Uw 0.9 / g 0.5 +shadir	2757	3771	2250	2587	3601	2080	2635	3649	2129
Uw 1.7 / g 0.35 +shad	2373	2988	2065	2047	2663	1740	1899	2514	1591

6.3.2. Sensitivity to orientation

The sensitivity to orientation has been assessed.

Table 23 Roof window life cycle cost sensitivity to orientation

	North					Central					South				
	west	north	east	south	west	west	north	east	south	west	west	north	east	south	west
Uw 6.6 / g 0.85	3641	4265	3638	3102	3641	2113	2634	2198	1600	2113	1473	1762	1504	1502	1473
Uw 3.2 / g 0.78	1605	1923	1625	1322	1605	964	1251	1023	705	964	1195	1227	1202	1313	1195
Uw 1.7 / g 0.6	1854	2032	1876	1692	1854	1561	1732	1602	1417	1561	1954	1917	1954	2069	1954
Uw 1.1 / g 0.5	2168	2296	2188	2050	2168	1984	2111	2016	1880	1984	2376	2327	2374	2479	2376
Uw 0.9 / g 0.5	2528	2642	2549	2421	2528	2385	2502	2416	2293	2385	2821	2759	2818	2929	2821
Uw 1.7 / g 0.35	2188	2345	2196	2049	2188	1857	1997	1885	1729	1857	1915	1942	1919	1963	1915
Uw 6.6 / g 0.85 +shading	3224	3823	3231	2718	3224	1856	2387	1930	1372	1856	720	1235	761	673	720
Uw 3.2 / g 0.78 +shading	1619	1962	1645	1327	1619	982	1315	1035	707	982	594	877	614	625	594
Uw 1.7 / g 0.6 +shading	2010	2218	2035	1833	2010	1689	1901	1726	1525	1689	1589	1747	1599	1636	1589
Uw 1.1 / g 0.5 +shading	2379	2534	2402	2246	2379	2164	2327	2193	2041	2164	2150	2260	2157	2198	2150
Uw 0.9 / g 0.5 +shading	2748	2891	2772	2626	2748	2570	2724	2599	2458	2570	2597	2695	2602	2649	2597
Uw 1.7 / g 0.35 +shading	2367	2535	2377	2224	2367	2036	2193	2061	1901	2036	1862	1983	1872	1878	1862

6.3.3. Sensitivity to cooling costs

The sensitivity to cooling costs has been assessed.

Table 24 Roof window life cycle cost sensitivity to cooling costs

	North			Central			South		
	cooling costs=ref	cooling costs*2	cooling costs*0.5	cooling costs=ref	cooling costs*2	cooling costs*0.5	cooling costs=ref	cooling costs*2	cooling costs*0.5
Uw 6.6 / g 0.85									
Uw 3.2 / g 0.78									
Uw 1.7 / g 0.6	1861	1920	1830	1578	1720	1502	1974	2757	1556
Uw 1.1 / g 0.5	2174	2224	2147	1998	2117	1934	2389	3039	2042
Uw 0.9 / g 0.5	2534	2584	2507	2399	2519	2335	2832	3481	2486
Uw 1.7 / g 0.35	2192	2224	2175	1867	1947	1824	1935	2398	1688
Uw 6.6 / g 0.85 +shading									
Uw 3.2 / g 0.78 +shading									
Uw 1.7 / g 0.6 +shadir	2021	2039	2021	1710	1758	1710	1643	1861	1643
Uw 1.1 / g 0.5 +shadir	2388	2406	2388	2181	2226	2181	2191	2389	2191
Uw 0.9 / g 0.5 +shadir	2757	2775	2757	2587	2633	2587	2635	2832	2635
Uw 1.7 / g 0.35 +shad	2373	2384	2373	2047	2081	2047	1899	2080	1899

6.3.4. Sensitivity to shading costs

The sensitivity to shading costs has been assessed.

Table 25 Roof window life cycle cost sensitivity to shading costs

	condition north			condition central			condition south		
	shading costs = 125 (ref)	shadings costs =200	shading costs = 75	shading costs = 125 (ref)	shadings costs =200	shading costs = 75	shading costs = 125 (ref)	shadings costs =200	shading costs = 75
Uw 6.6 / g 0.85									
Uw 3.2 / g 0.78									
Uw 1.7 / g 0.6	1861	1861	1861	1578	1578	1578	1974	1974	1974
Uw 1.1 / g 0.5	2174	2174	2174	1998	1998	1998	2389	2389	2389
Uw 0.9 / g 0.5	2534	2534	2534	2399	2399	2399	2832	2832	2832
Uw 1.7 / g 0.35	2192	2192	2192	1867	1867	1867	1935	1935	1935
Uw 6.6 / g 0.85 +shading									
Uw 3.2 / g 0.78 +shading									
Uw 1.7 / g 0.6 +shading	2021	2180	1914	1710	1869	1603	1643	1802	1536
Uw 1.1 / g 0.5 +shading	2388	2555	2277	2181	2347	2070	2191	2358	2080
Uw 0.9 / g 0.5 +shading	2757	2924	2646	2587	2754	2476	2635	2802	2524
Uw 1.7 / g 0.35 +shadin	2373	2533	2267	2047	2207	1941	1899	2059	1792

6.4. Conclusions LCC

For most variations of cost assumptions the relative ranking remains largely the same. Of course the LCC varies with varying economic conditions, but the results are in line with what can be expected: If energy costs increase (e.g. by increased escalation or lower efficiency for cooling) the windows with better energy performance become more attractive, etc.

However, when the performance per orientation is taken into account, the results for the Southern climate condition are less predictable and show a larger change in relative ranking according life cycle costs. Where the uniform distribution shows relative low LCC's for windows with shading devices, the results per orientation show that this holds true for East and West oriented windows, but not for North and South oriented windows: For North oriented windows the shading device mainly adds costs, for South oriented windows the optimal balance of Uw and g-value is shifted towards windows with a higher Uw and higher g. This is less true for roof windows as the relative differences in solar irradiance are less pronounced.

It should be mentioned that the above conclusions are based on assumptions regarding purchase costs and energy performance as stated in the report. These assumptions may be different depending on window location, type, frame material and application (type and use of building, plus its context) so should not be interpreted as universally applicable, regardless of application, etc.

CHAPTER 7 LONG-TERM TARGETS (BNAT) AND SYSTEMS ANALYSIS

This paragraph looks beyond the window products that are currently on the market to consider what technical potential could be further developed and what could be the role of windows in the future. Also aspects that must be discussed together with the replacement of windows are addressed.

7.1. INSTALLATION OF THE WINDOW IN THE BUILDING

When considering the window as an overall system, including the wall connecting joints, one discovers more potential for optimisation as the transition between window and external wall usually has a linear thermal bridge; the loss of energy through this bridge is indicated by the Ψ-value and can be taken into account by adding a tolerance of ΔU to the entire building envelope. But also the consideration of thermal bridges by means of detailed calculation is possible. With thermally optimised jointing details – for example by applying insulation to the outside of the frame member – it is possible to achieve very small, and even negative, values. With poor detailing of the wall connecting joints the energy loss through the joints may even be greater than that through the entire window. In terms of energy, the reduction of the Ψ-value by 0.12 W/m K is equivalent to reducing the U-value of a standard-sized window (1.23 x 1.48 m) by ΔU_W = 0.4 W/(m² K).

Thermal bridges are local thermal weaknesses in the building envelope in general in the shape of a line. They can occur e.g. at the junction of different building components or where building materials with differential thermal conductivity are used; they result in increased heat flows (Φ) and consequently lower internal surface temperatures (θ_{si}). This not only increases heat loss, but also brings about the risk of condensate formation which in turn can lead to the growth of mould; therefore great attention should be paid to this issue. For this reason, national requirements should contain detailed requirements regarding minimum thermal insulation and the prevention of condensate and mould growth.

A proper installation also has to guarantee the durable air tightness at the window wall interface to

- Minimize the heat losses by infiltration and to
- Avoid condensation in the gap between the window and the wall.

Replacement of windows is often very extensive because the removal of the old window has in general an enormous impact on the surrounding wall. Often larger areas of the relevant interface of the wall are demolished, the replacement is very dirty. The development of installation systems or special installation frames allowing an easy replacement of the windows also in the future could be an approach to avoid these negative impacts.

The installation of the window is also affected by the improvement of the thermal transmittance of the wall. In the last years bricks were developed with very low thermal conductivity. With these bricks very low U-values of walls can be achieved without using additional thermal insulation material. But the negative effect is that together with the thermal conductivity also the mechanical properties of such bricks are decreasing. Simultaneously windows are getting bigger and bigger, heavier IGUs are installed (e.g. triple glazing, laminated glazings, etc.). As a consequence the loads on the installation hardware and the loads on the wall are increasing but the high insulation bricks are not able to cope with these loads. Therefore new techniques for the installation of windows in highly insulation walls (made out of bricks) must be developed.

Considering a window as a component of the overall product, i.e. the building, the quality and nature of the installation become important factors – equally if not more important than the performance of the window measured in isolation. The design of the junction will influence thermal bridging effects in particular. In addition, poor installation will result in a gap between the as-built and designed performance. A recent UK study[12] identified that windows were being installed forward from their design position resulting in insufficient overlaps with cavity closers, leading to greater heat loss from thermal bridging; plus the tolerances around windows were considerably out, which would lead to increased heat loss from thermal bridging. Among the recommendations given in the report to address these issues was the introduction of an industry recognised card scheme to enable operatives and professionals to demonstrate that they have the necessary

[12] Closing the Gap between Design and As-Built Performance: End of Term Report, July 2014, Zero Carbon Hub.

energy performance knowledge and skills. Therefore it is vital that any initiative designed to improve the energy efficiency of buildings also addresses this critical skills issue.

7.2. Energy-efficient ventilation

Sufficient ventilation of habitable rooms is a mandatory requirement for health and construction reasons; the standard requirement is approx. 30 m^3/h per person. Additional ventilation may be required in rooms with open combustion appliances (fireplaces, solid fuel burners) and equipment creating emissions, such as computers, printers and household appliances. Likewise, any excess humidity in the air must be reliably removed from the interior in order to prevent the formation of condensate and mould. The humidity generated from showers, plants, cooking or washing depends very much on individual habits; it is therefore preferable to control the relative humidity with hygrometers in order to maintain it within the ideal range of between 45 to 60%. It is often the case that following an upgrade refurbishment of a building, the relative humidity increases in the interior and leads to the formation of mould; this is due to the fact that there are no longer joints and cracks that contribute to ventilation, and the controlled ventilation is inadequate. Due to the changes in ventilation habits and living patterns, manual window ventilation (airing) may no longer be adequate to ensure that humidity does not rise beyond acceptable levels. For this reason the traditional method of “window ventilation” should be developed further, for example by installing motorised opening mechanisms, new hardware functions or ventilation systems integrated into the window (so-called window ventilation devices or “vents”). Window vents are suitable for installation with replacement windows, in newly built and for retrofitting to existing windows. They are particularly suitable for building refurbishment where clients may be concerned about condensation and mould formation issues.

Also related to ventilation is an increased ventilation rate at night times, to remove heat build-up during the day ('ventilative cooling'). Also during the day, when outdoor temperatures are lower than indoor, increased ventilation can be used to reduce the cooling load (often by opening of windows, if circumstances allow).

The combination of roof windows with façade windows can allow for a stack effect (provided indoor air flow supports this).

7.3. Shutters

Some of the technologies presented are already available for shutters. For example, automated systems become more and more used on the market and can be connected to heating and cooling system so that the energy balance of windows is optimised. Intelligent shading systems do already exist for the roof window category, and can be combined with ventilative cooling. Shutters can also be connected to alarm systems for security purposes.

7.4. Safety and comfort

Although a high energy efficiency can be regarded as an absolute necessity, personal purchase decisions are also influenced by other requirements and also emotions. For buildings, this means more security, comfort, health and better presentation. Security for windows is one of the standard features and is achieved at present by suitable fittings and glazing. In the near future, automatic closing systems and a centralised building locking system with sensors in windows, doors and glass could become standard, and these will promptly send a message to a smartphone and to the nearest police station in case of damage or break-in. Sensors and electrical systems will also fetch a substantial plus for health, by ensuring adequate ventilation in a decentralised and natural manner via windows, which, if needed, can be opened or closed automatically, if the target values for humidity and CO_2 content have been reached. Thus, condensation and poor quality of air become a thing of the past – possibly even without fans. In summer, the automatic windows can be used for natural cooling at night, without you having to wake up in case of thunderstorms, since the rain sensor in the window will close the windows automatically. The levels of comfort by automatic windows and doors will then be taken for granted, particularly for older persons or handicapped people. The operation will then be user-friendly and intuitively via smartphone, so that it meets the human need, that is of controlling your own living environment independently and effortless.

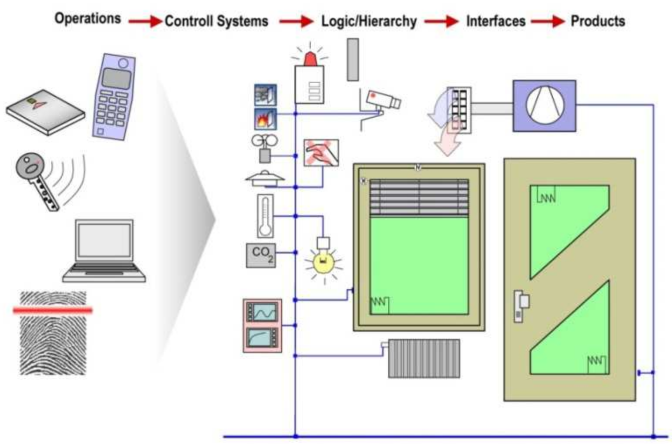
Manufacturers must grapple very intensively with the development of simple and intuitive control elements so that the consumer is able to use these products of greater complexity with ease in the future. The developments in the field of entertainment electronics and smartphones are already setting standards today, and they will soon also include the construction and living room segments. What is still visual control at present will be superseded tomorrow by voice commands. The design principle of the universal design offers a comprehensive approach for the development and utilisation of innovative products and construction elements. The objective of universal design is that as many human beings as possible with different levels of knowledge and capabilities should be able to use products and services easily and safely.

The levels of comfort and visual well-being are also enhanced by innovative glazing units. Glass surfaces in the future will be capable of being darkened or used as multimedia screens, which work like an LED monitor screen[13]. Even today, small and barely visible LED elements turn the glass into a screen, if needed. Multimedia facades, which still comprise individually controllable LED strips today, will soon be replaced by flexible organic LED films (OLED)[14], which can be applied easily on any shapes and materials. Organic LED cells make this possible, for which cost-effective print methods are presently being developed[15], with the help of which the costs can be reduced and customized products can be produced in small quantities. OLED (Organic LEDs) are a few nanometres thin, self-emitting thin, flexible light sources, which consist of organic semiconductors and form the basis for thin, flexible displays with shining colours and high level of contrast. Organic LEDs are already being used at present in MP3 players, cameras and mobile telephones and they will find their way into the multimedia facade. Their high level of colour rendering index, their natural white light and the good degree of energy efficiency are beneficial.

7.5. Electronics and the Internet

The opportunities of the Internet and mobile terminal devices are still in the initial stages, and we just cannot foresee today how intensively this technology will yet penetrate into our lives. The initial approaches are being manifested in the automotive industry, which is already working on autonomous and self-controlling vehicles[16]. Since recent times, suppliers from the automotive industry[17] are also providing electromagnetic components for the windows and fittings segment, and are bringing dynamism into the construction sector with their experience, competence and economic strength. This is why in a few years from now, electrically operated windows and doors with intelligent sensor technology will be the standard for sophisticated building control equipment. Particularly for older or handicapped people, automatically opening doors and windows provide a big plus in the quality of living. Companies that use this technology and gather experience at an early stage will then be one of the gainers. The basis for standardised electrical interfaces have already been worked out[18] and are being discovered as a mass market and undergoing advanced development by providers from other industries (automotive and electronics).

Figure 7 Mechatronic windows and doors require user interfaces



[13] Glass Innovations, Corning Incorporated, „A Day Made of Glass“ (www.corning.com/adaymadeofglass/index.aspx)

[14] R & D project, funding initiative, „OLED Lighting – So-Light“, BMBF, Dresden 31 December 2012

[15] Printing process for organic light-emitting diodes, Fraunhofer magazine (www.fraunhofer.de/en/publications/fraunhofer-magazine/archive)

[16] Mercedes-Benz „Intelligent Drive“(http://techcenter.mercedes-benz.com/en

[17] Brose -Technik für Automobile, „Spindle drives for lift gates“ (http://www.brose.de/ww/en/pub/products/vehicle_doors_and_liftgates/systems_for_liftgates.htm)

[18] ift Guideline EL-01engl/1 „Electronic systems in windows, doors and facades“; publisher: ift Rosenheim (www.ift-rosenheim.de/web/portal/literaturshop)

The enormous performance capability of electronic control systems in the future will be based on the principles of data mining[19]. This may foster self-learning control mechanisms that identify the specific habits of the users quickly and certainly, and provide comfortable temperature, lighting conditions and fresh air accurately. They also lock all windows when the front door is closed.

While the costs of advanced sensor, actuation and communications technologies are falling, it remains to be seen when it will become cost effective to build such a „smart", automated building. In the meantime, it is important that the consumer is properly educated in how all the elements of their building work best together, including their windows, and for product designers to embrace concepts such as Universal Design.

7.6. Demographic development and Universal Design

The low birth rates in Europe and the continuous rise in life expectancy lead to an increasing proportion of older human beings. As a result of this demographic change, human beings aged 55+ with considerable purchasing power (Silver Agers), increasingly influence the social values as well as products and services. This target group attributes great importance to its own real estate property and comfort, security and freedom from barriers have the highest priority for construction – all of these being requirements that can be described and designed well with the design principles of Universal Design (UD). Today, UD is already being applied frequently for items of day-to-day need, mobile telephones, motor vehicles, health, transport as well as simple operation and control of electronic devices. In the living segment, kitchen and bathroom areas are being designed according to the criteria of UD. Soon, other segments of the construction industry will be covered by this trend – in particular, even the manufacturers of doors, gates, windows and construction fittings, since their products are essentially functional construction elements.

The design features of the universal design can be well described with the help of 7 principles:

1. **Wide usability**

   The design can be used and marketed for human beings with different levels of capabilities and skills.

2. **Flexibility in use**

   The design supports a wide range of customised preferences and options.

3. **Easy and intuitive use**

   The use of the design is easy to understand, independent of experience, knowledge, linguistic capabilities or instantaneous concentration of the user.

4. **Information that can be processed with sensory perception**

   The use of the design is easy to understand, independent of experience, knowledge, linguistic capabilities or instantaneous concentration of the user.

5. **Fault tolerance**

   The design minimises risks and the negative consequences of coincidental or inadvertent actions.

6. **Low level of physical effort**

   The design can be used efficiently and comfortably with minimum fatigue.

7. **Size and space for entry and use**

   Provide reasonable size and space for entry, reach, manipulation and use regardless of the size of the user, his/her posture or mobility.

This is why UD will need to be taken into consideration to a much larger extent in future for design and product development. In future, the demand will be for products that combine design with suitable functionality. A core issue in the process will be freedom from barriers. According to the German study „Housing for the Elderly"20, there is a short-

[19] Research Center „Berlin Big Data Center (BBDC)"(www.bmbf.de/press/3580.php)

[20] Wohnen im Alter, (Housing for the Elderly), Study Forschungsheft (research journal) 147, Federal Institute for Building, Urban and Space Research, 2011

term need for additional 2.5 million homes suitable for senior citizens in Germany, which will rise to three million until 2020. There are doorsteps in 50 % of all residential units, and these are perceived as barriers, particularly at the entry to the balcony or the terrace.

This is why with the design features of Universal Design (UD), the simple and safe use of windows, is coming increasingly into focus apart from the popular performance characteristics such as thermal insulation, sound insulation and fire safety or deformation stability. Buildings and building elements must be flexible and easy to change so that the building and living space continue to work even with changes in the user groups and the user behavioural patterns. This is the case, for example, if the occupants of a building become older, or other requirements come up with sickness or accident, if grandparents move in or small children get added to the family. This is why the flexible use of buildings and building elements is becoming increasingly more important and more accurate analysis of the user needs and product characteristics from the perspective of different users are necessary. Here, too, the holistic concept of the UD provides advantages with the solution of these tasks in the future.

7.7. MATERIAL SCIENCES AND NANOTECHNOLOGY

The development of new materials made of metal and plastics as well as composite constructions facilitates the production of filigree window and facade profiles of high strength with excellent thermal insulation properties that permit even more sunlight into the house. In the project “Development of light-weight profiles and building components made of fibre-reinforced plastics for applications in the textile building shell and window equipment”21, construction guidelines for dimensioning as well as suitable and cost-effective manufacturing methods (pulltrusion processes) have been worked out for FRP (Fibre-Reinforced Plastics) profiles.

Figure 8 ULTRASLIM Innovative window profiles based on FRP profiles[22]

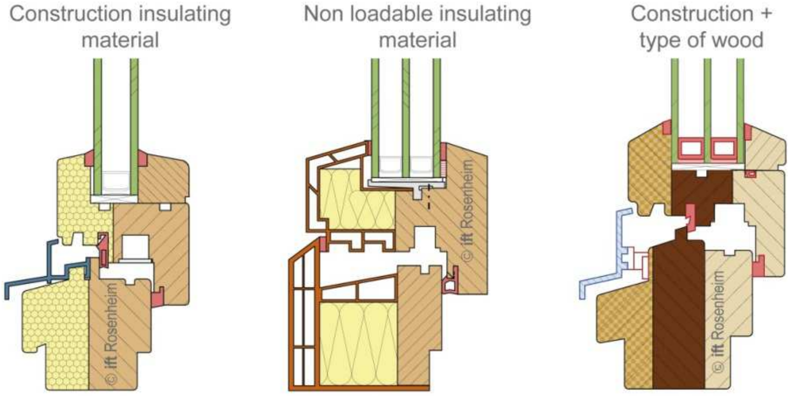
The basics for using thermal methods to improve the wood-related properties as well as constructional basics for composite constructions were established for wooden windows in the project “Sustainable optimisation of wooden window profiles”23. This makes it possible to improve the properties of wooden window profiles with respect to the strength, thermal insulation and resistance to weathering. Thus, Uf values of 0.6 W/(m² K) can be achieved for the frame, which then form the basis for windows having high levels of thermal insulation with UW values less than 0.4 W/(m²K). Even the use of decorative types of wood such as that of the cherry tree, mahogany or other precious timber is facilitated – this supports the trend towards unique designer windows made of wood.

[21] R & D project of the research initiative Zukunft Bau „Development of light-weight profiles and building components made of fibre-reinforced plastics for applications in the textile building shell and window equipment (PROFAKU)“, Fraunhofer IRB Verlag, 2010, 139 pages., ISBN: 978-3-8167-8719-8

[22] Picture: FH Dortmund

[23] R & D project of the research initiative Zukunft Bau „Sustainable optimisation of wooden window profiles to achieve compliance with the requirements of EnEV 2012“, ift Rosenheim, ISBN: 8-3-86791-284-6

Figure 9 High-performing wooden windows



Very low U_g values can also be achieved by vacuum glazing, but this type of glazing is not yet available as commodity product, therefore it is considered a best not (yet) available technology.

Warm edge spacers however are becoming mainstream and help to (slightly) improve the overall energy performance of windows.

At the moment there are four EU funded projects tackling the improvement of windows by means of development and usage of new materials.

- HARWIN: Harvesting solar energy with multifunctional glass-polymer windows. (http://www.harwin-fp7.eu/). Project topics are:
  - Laminated glass containing nanomaterials, not yet utilized for glazing;
  - Glass-polymer composite interlayers (mechanically reinforced materials, weight reduction, high visible light transmission, thermal and sound barrier properties);
  - Latent heat storing elements (additional energy harvesting);
  - Polymer foam-basalt fibre-reinforced framing (weight reduction);
  - Life cycle assessment of various types of windows to create a benchmark to which compare the innovative window options. This assessment covered development of: A project-specific life cycle based, multi-criteria (14 impact categories of PEF) iterative LCA method was developed, to be used in ecodesign tools for the design team. and a recyclability analysis method involving recyclers[24];
- MEM4WIN: Ultra-thin glass membranes for advanced, adjustable and affordable quadruple glazing windows for zero-energy buildings (http://www.smart-frame.eu/site/node/102):
  - Tempered ultra-thin glass membranes (thickness of ~0.9 mm)
  - Anti-reflective coating (plus 3 per cent transmission)
  - Innovative frame assembly for a four-pane structure (U_g value: 0.3 W/m²K), which also allows for a frameless, open able wing in full-glass façades
  - Sealing for the integration of PV and OLED
- SMARTBLIND project aims at developing an Energy Efficient Smart Window including a hybrid film constituted of an electrochromic LC film and a photovoltaic film both printed on the same long-lasting flexible substrate. A

[24] K. Allacker, C. Baldassarri, M. Calero, F. Mathieux, Y. Roderick, "Using life cycle based environmental assessment in developing innovative multi-functional glass-polymer windows", Proceedings of SB13 Conference, Sustainable building conference 2013, 25-28 September 2013, Graz, Austria

reduction of the windows U-value down to 0.3 W/m².K is targeted by combining the hybrid film to an appropriate window frame. (http://www.smartblind-project.eu/):

  - To reduce weight by 50% compared to glass window, while offering transparency and flexibility.
  - To improve the optical response time of windows while enabling the switching of large panes.
  - To integrate an electronic control system with an embedded power source.
  - To guarantee a low-cost industrial solution adaptable to large and shaped surfaces.

- WINSMART Smart, lightweight, cost-effective and energy efficient windows based on novel material combinations (http://winsmart.dti.dk/):
  - Reduce the U-value from 0.8 to 0.3
  - Reduce the weight of the window by 50%
  - Reduce the window's overall energy consumption (embodied energy) during the manufacturing process and disposal/recycling by 50 %
  - Use new materials and new technology to improve the construction of the window frame and framework, the vacuum window and the glass coating
  - Develop smart technologies to control the solar radiation through the window
- EXTRUWIN - Extruded window profiles based on an environmentally friendly wood-polymer composite material[25]:
  - The objective of this research project is to develop and manufacture a wood-plastic composite window profile for the European market. The consortium will systematically investigate all steps required to produce a WPC window profile prototype, including identification of suitable raw materials for formulations (natural fillers or fibres, thermoplastics (PP, PE, PVC), coupling agents, UV protection agents, etc.), compounding, extrusion, die manufacturing, profile bonding, and development of suitable coatings.

- THINFRAME (http://www.thinframe.eu/)
  - THINFRAME includes the development of an insulating foam material made of polystyrene (PS) and polyethylene (PE) filled with a Phase Change Material (PCM). It will be processed in-line with the PVC profiles made by extrusion and will provide ease of adaptation to current production methods of the industries involved, lower heat loss of the windows installed (U-value of the frame lower than 0.7 W/m2K), improved energy efficiency of buildings (savings of energy and CO2 emissions at European level) and cost-effective solution able to compete with PVC systems of lower insulation properties.
- CLIMAWIN and CLIMAWINDA (http://cordis.europa.eu/project/rcn/108386_en.html)
  - The CLIMAWIN consortium, a group of European SME manufacturers and suppliers of windows and ventilation systems, aims at developing a novel high performance window with electronic operation of an auto-regulated natural ventilation system and electronic insulating night blind powered by solar power.

[25] http://www.healthcompetence.eu/converis/publicweb/project/1266

Further information can be found on the according websites.

Since the EC Commission is encouraging the cluster activities between inter-organizational sister projects, the above mentioned FP7 Projects joined in the cluster of Smart Windows Projects. JRC-IES-H08 is coordinating the discussion on Life Cycle Assessment as a tool to make environmental informed choices during the development of innovative windows. The objective is to share knowledge/info/data on the most relevant open issues on LCA of windows. Relevant topics has been selected as priorities to be discussed within the members of the cluster. Among this topic there is the definition of a benchmark scenario representative of State-of-Art windows to which compare the innovative products, reliability of databases for secondary data, primary data gathering, recyclability of windows and components, definition of the functional unit and of the life span.

Beside this activity JRC IES-H08 is working on recommendations for a better integration of LCA into inter-organizational R&D projects, focusing, through the work on HarWin Project, on how to increase the effectiveness of LCA as instrument for guiding ecodesign of innovative windows.26

[26] C. Baldassarri, F. Mathieux, F. Ardente,:" A life cycle method to support the design of innovative windows",25 November 2014 - Novi Sad, SETAC 20th LCA Case Study Symposium – "LCA in promoting eco-innovation and sustainability: education, research and application"