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PROJECT FINAL REPORT

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Project acronym: HARWIN

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4.1 Final publishable summary report

4.1.1. Executive summary

Very ambitious technical key objectives for new window concepts were defined by the EeB Smart Windows Program EeB.NMP.2012-5 in the Seventh Framework programme:

- Energy savings over live cycle up to 15%
- Weight reduction up to 50%
- Insulating window with 0,3 W/m²/K at VLT > 50%

The HarWin approach to fulfil these goals is based on material development for both: the window glazing and the frame.

Weight and energy demand reduction over the life cycle is achieved by selection of lightweight materials with low embodied energy and by simultaneous improvement of the mechanical and thermal as well as optical performance of these materials by utilization of most advanced strengthening methods for glazing and frame, and by reduction of thermal conductivity of polymer-glass composites.

Energy harvesting is based on use of Phase Change Materials (PCM) in the glazing as additional thermal mass and new glass with Luminescent Down Conversion (LDC) properties to increase the Visible Light Transmission (VLT).

With thin glass laminated panes reinforced with new polymer-glass composite materials performance figures of U-value (0.4 W/m²/K) and VLT (75%) comparable or even superior to existing triple glazing can be achieved at almost 50% lower weight.

The new extremely stiff and thermally insulating frame, based on polymer foam core-glass fiber reinforced polymer skin materials offers additional embodied energy savings due to weight reduction by a factor of 5-10 as compared to existing polymer/metal or metal frame.

In addition to development of new materials also simulation methods have been developed for the next generation of light weight windows, which due to their modular structure also enable extension of window functionality, like wavelength specific energy management, including wave length conversion with coatings but also with a new active luminescent glass and with PCM (phase changing materials).

A data base and a simulation tool which is including End of Life (EoL) recycle ability of materials were developed for LCEA analysis of HarWin windows. Furthermore, a HarWin window module for building performance simulation has been implemented into existing sophisticated building performance software (Virtual Environment, IES, UK). Extensive characterisation of optical and thermal properties of HarWin windows enabled the implementation of a data base for the new materials into a cost analysis tool, which is used to validate the cost saving potential of the new window materials.

The benefits of the light weight glazing and frame materials in terms of energy and cost savings and in particular for refurbishment of old buildings were clearly demonstrated. For energy harvesting with the help of PCM a thorough analysis of inorganic and organic materials has been accomplished, showing the superiority of organic materials for achievement of high light transmission. Even thin layers of PCM have proven to offer energy savings for cooling in certain climatic zones.

For harvesting the UV part of sun radiation for increased VLT a new Luminescent Down Conversion glass has been developed which converts UV radiation into visible range of wavelengths with almost 30% photonic efficiency.

4.1.2 Summary description of project context and objectives

Work performed since the beginning of the project is divided into two areas: I. Material and component development for Smart Windows and 2. Development of simulation and LCEA methodology for windows to define energy savings over life cycle as well as added value and building constraints. The material and component development includes the following Workpackages: WP1, Material development for light weight glazing; WP 2 Added functionality for solar energy harvesting; WP3 Laminated composite glazing components with added functionality; WP 4 Light weight frame and glazing. The simulation and LCEA methodology development includes two Workpackages: WP 5 Modelling of glazing constraints, component performance and building integration; WP 6 LCEA of windows integrated in buildings. The following main results were achieved:

- Energy savings over live cycle up to 15% were reached and even exceeded. Based on experimental data obtained from HarWin Demonstrator glazing and frame energy savings over life cycle were shown to be achievable up to 25% of total energy for heating and cooling.
- The degree of energy consumption reduction depends upon building type: a detached single family house versus an office building or apartment, and the climate zone as well as the character of the building, e.g., new versus refurbished old were included in different building simulations.
- In addition energy saving is achieved by reduction of amount of materials used as well as by use of materials with high recycle potential. Quantitative results from a new LCEA tool developed in HarWin were used to guide the material and component development. Life Cycle Inventory datasets for the applied materials were established.
- Weight reduction of almost 50% (triple glazing) is achieved with new laminated and particle reinforced thin glass panes and new light weight frame. A weight reduction of 47% is achieved for triple glazing with specialized laminated glass panes. Compared with state of art triple glazing thin glass particle reinforced laminated panes have the capability for the required mechanical strength. In addition a light weight frame has been developed which would further reduce the overall weight of multiple glazing windows.
- Insulating window with 0,3 $W/m^2/K$ at VLT >50%: The required U value reduction cannot be achieved with single laminated panes with optimized reinforcing particle amount and geometry but based on thin laminated glass panes reinforced with such polymer-glass composite interlayers multiple glazing was developed with UG value of 0.4 W/m^2K at VLT of 75%.
- The weight reduction potential of the newly developed frame has not been added to the overall weight reduction figures because of the low TRL of the frame manufacturing and testing. From LCEA analysis the high innovation potential of such light weight frame materials has been clearly shown, in particular if strengthening is done with the help of Basalt Glass fibers developed in HarWin.

Energy savings over live cycle up to 15% were reached and even exceeded (WP1-5). Based on experimental data obtained from HarWin Demonstrator glazing and frame energy savings over life cycle were shown to be achievable up to 25% of total energy for heating and cooling. The degree of energy consumption reduction depends upon building type: a detached single family house versus an office building or apartment, and the climate zone as well as the character of the building, e.g., new versus refurbished old were included in different building simulations. In addition energy saving is achieved by reduction of amount of materials used as well as by use of materials with high recycle potential. Quantitative results from a new LCEA tool developed in HarWin were used to guide the material and component development. Life Cycle Inventory datasets for the applied materials were established.

Insulating window with 0,3 W/m²/K at VLT >50% (WP1,3). The required U value reduction cannot be achieved with single laminated panes with optimized reinforcing particle amount and geometry but based on thin laminated glass panes reinforced with such polymer-glass composite interlayers multiple glazing was developed with U_G value of 0.4 W/m²K at VLT of 75%. The weight reduction potential of the newly developed frame has not been added to the overall weight reduction figures because of the low TRL of the frame manufacturing and testing. From LCEA analysis the high innovation potential of such light weight frame materials has been clearly shown, in particular if strengthening is done with the help of Basalt Glass fibers developed in HarWin.
The general technical features of the different Demonstrator variants are shown in Figure 1 and performance figures are shown in Table 1.

LCA, LCC, Building simulation (WP 1-6). The LCA tool developed in HarWin enables for the first time a quantitative analysis of contribution of different windows to buildings environmental impact. This methodology is capable of guiding further development of smart windows. It was already used in HarWin to improve the construction and reduce the embodied energy of the new light weight frame and to show added value of new materials, like e.g., basalt glass and glass flakes. Photographs of HarWin glazing and window Demonstrators are shown in Figure 2. The key exploitable results and their potential users are summarized in Table 2.

Prototype	Setup	Glazing	Added functionality
Demonstrator 1	Double glazing 3mm pane, low e-coating 5vol% glass flakes >5-7% haze		Stiffness increased, VLT preserved, U-value <1.5 W/mK
Demonstrator 2	Tripple glazing, 2 mm pane, low e-coating, 15vol% glass flakes, ~3-5% haze		Higher stiffness, weight reduction glazing 25%, low U value (0.5 W/mK)
Demonstrator 3 (A+B)	A: tripple glazing, 1.6 mm pane, chemically strenghtened, AR& low e-coating, 15vol% glass flakes, ~2% haze (n_D optimized glass flakes), PP-GF reinforced frame B: tripple glazing, 1.6 mm pane, 3 mm PCM		Higher stiffness, weight reduction w. frame 47%, combined AR & low e-coating, PCM functionality

Figure 1.: Technical features of HarWin Demonstrator variants.

	Standard triple glazing glass 4 low-E// glass 4 // glass 4 low-E	Demonstrator III triple glazing laminate glass 2x1.5-0.5 PVB(15%GF)-AR//glass 1.5 low E// glass 1.5 low E	Demonstrator IV triple glazing laminate glass 2x1.5-0.5 PVB(15%GF)-AR//glass 1.5 low E// glass 1.5 low E
Weight glazing [kg/m²]	30	15.7	15.7
weight reduction [%]	-	47.7	47.7
gas filled gap dimension [mm]	18/18 (Ar)	6/6 (Ar)	18/18 (Ar) or 14/14 (Kr)
calculated U_G-value [W/m²K]	U_G = 0.50	U_G = 1.30	U_G = 0.49 or 0.41
measured U_G-value (DIN EN 674) [W/m²K]	U_G = 0.60	-	-
VLT (visible light transmission) [%]	T_{VIS} = 71	T_{VIS} = 74.5%	T_{VIS} = 74.5%
energy transmission [%]	T_E = 43	T_E = 36.7%	T_E = 36.7%
optical haze [%]	< 0.5	1.7%	1.7%

Table 1. HarWin Demonstrator performance figure

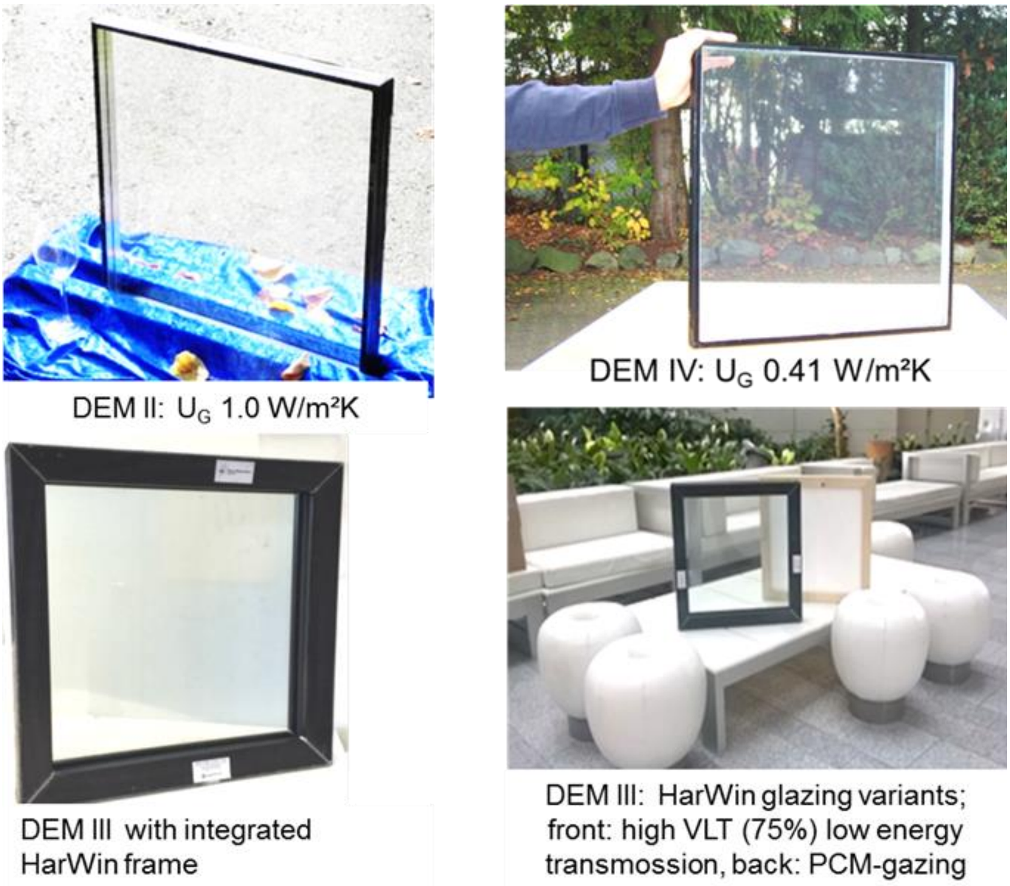


Figure 2.: HarWin Demonstrator glazing variants and windows with glazing 500x500 mm²

Exploitable Result	Key Partner	Key Performance Criteria	Potential user
Reinforced composite polymer foils for thin glass lamination	UBT, (GE) InGlas (GE)	PVB with stiffness varying from 10 MPa to 10 GPa, stable Tg, adjustable sound absorption, superior moisture barrier properties, haze comparable to pure PVB.	SME, Industry
Thin glass reinforced laminate multiple glazing	UBT, (GE) InGlas (GE)	Weight reduction of glazing by ~50% (compared to triple glazing), U-value 0.50 W/m²K (Ar filling), safety glass features, noise protection	SME, Industry
Light weight polymer-GF reinforced polymer foam frame	UBT, (GE) InGlas (GE) WUT (PL), Isomatex (B)	Thermal conductivity of the polymer-foam-polymer skin composite 0.05 W/mK, very high stiffness due to glass fibre reinforced polymer skin, light weight.	SME, Industry
New LCEA methodology and simulation tool	JRC Ispra (Italy)	Feature specific tool for the eco-design of windows, multi criteria life cycle impact assessment, recycleability analysis method	Citizens, public bodies, environmental agencies, industry,
Building simulation tool for HarWin glazing	International Environmental Solutions, IES (UK)	HarWin type windows data base implemented into <VE> building simulation program, LCC analysis for new windows, cost reduction for refurbishment of buildings demonstrated.	SME, Architects, citizens, environmental agencies

Table 2. HarWin key exploitable results and their potential users.

4.1.3 Main S&T results/foregrounds

WP 1 Material development for light weight glazing

Summary

i. The material development for HarWin glazing follows the concept of decoupling of mechanical and thermal properties from the visible light transmission and sound characteristics of the glazing, by designing polymer-glass composites with different structural features at the micro-, meso- and macro scale. Using the guidance from simulation different manufacturing methods were tested to arrive at the desired microstructure of the composite interlayers and to find an optimum between stiffness and weight of the glazing at the macroscale. A very good agreement is achieved between mesoscale simulation and experimental verification of the elastic and sound damping properties of the composite interlayers.

ii. Experimental verification of thermal properties of the polymer-glass composites has shown a very good matching between simulated and real thermal properties. The results of thermal measurements combined with experimental results of Visible Light Transmission (VLT) and haze measurements on such composites revealed the conflict to achieve a very low thermal conductivity with polymer-glass particle interlayers at the required high VLT and low haze values. Lowering of the U-value at macroscale of a window is therefore achieved with gas filled gaps in a light weight multiple glazing.

iii. For the achievement of a high VLT and low haze of polymer-glass particle composites a perfect matching of refraction index between the polymer and the glass particles has been found to be crucial. This has been accomplished by adjustment of glass composition and melt-based manufacturing of glass flakes for assembly of the 3rd stage Demonstrators.

iv. Besides optimization of the polymer-glass particle composites also different methods to laminate thin glass panes with the newly developed polymer-glass flake composites were investigated with the goal of perfect connectivity between the composite interlayers and the thin glass panes.

v. LCI (Life Cycle Inventory) data sets and basic LCA methodology of glass flake polymer composite materials and for light weight frames were developed to enable analysis of the specialized HarWin windows benefits as compared to state of art triple glazing windows.

The material concept developed in HarWin for light weight glazing based on polymer-glass composites is shown in Figure 2.1-1.

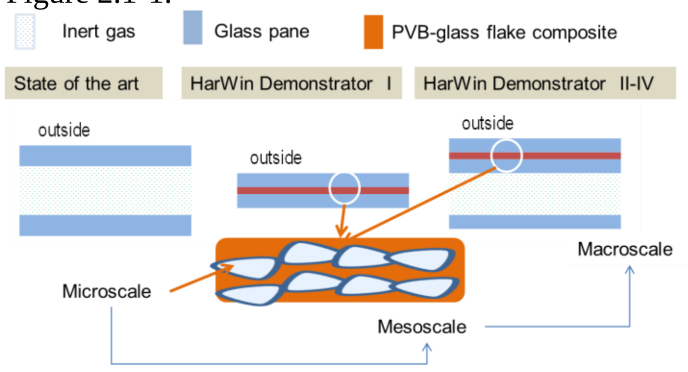


Figure 2.1-1.: Material concept for HarWin glazing.

Mechanical and optical properties of polymer-glass composites and of laminate glazing

The focus for material development is to achieve simultaneously weight reduction, high VLT, low haze and high acoustic damping for the glazing. Addition of a significant volume fraction of glass particles to a polymer interlayer enables increase of stiffness but worsens the VLT and haze and disables acoustic damping as well as "safety" glass characteristics. State of the art polymer interlayers contain polymeric softeners to improve acoustic damping and toughness of the laminate glazing. A systematic investigation has therefore been performed to find the optimum of volume percentage of glass additives and softener containing polymer compositions, as shown in the left part of Figure 2.1.-3. The effect of glass flake addition is compared with glass fiber reinforcement of polymers, e.g., Polypropylene [1,2], as shown in the right part of Figure 2.1-3. A remarkable difference is found with respect to the strengthening effect of glass flakes as compared to fibers. While upon glass fiber addition above 15vol% the "efficiency factor" for stiffening decreases due to fiber miss-orientation in case of glass flakes at contents above 15 vol% the efficiency remains high, particularly for larger glass flakes of 200 µm size.

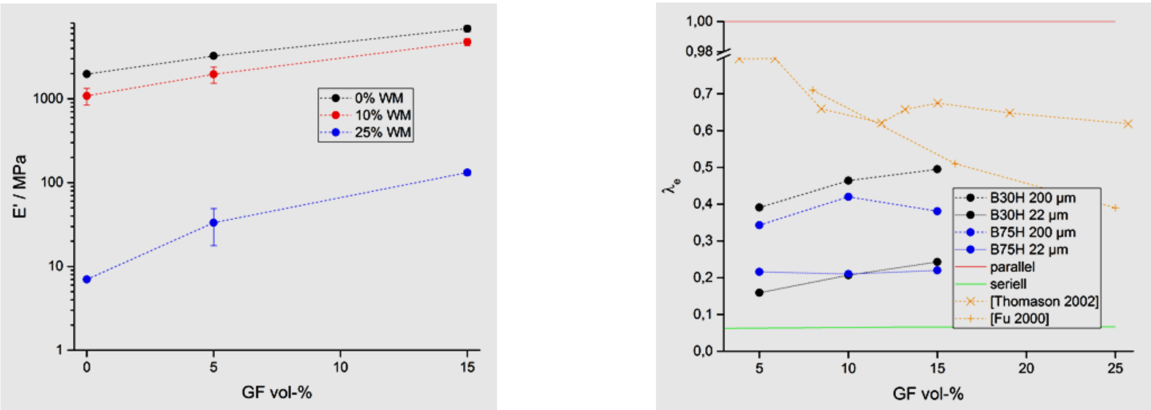


Figure 2.1-3.: left: Storage moduli (at 25°C) as a function of glass flake and softener (WM, Weichmacher) content of a PVB-glass flake composite interlayer measured by means of dynamic mechanical analysis; right: efficiency factor for stiffness increase upon glass fiber addition as compared to glass flake addition

The coupling through the PVB-glass-flake composite improves the mechanical properties of the glazing structure, as has been shown by macroscale simulation (for details see D 1.9). In Figure 2.1-4 the results of simultaneous improvement of mechanical properties and weight reduction for HarWin glazing panes are shown.

The beneficial mechanical effect of glass flake reinforcement requires special care for simultaneous achievement of the required high VLT (> 50%). The refractive index mismatch of the glass particles to the polymer is the cause of reduced clarity and increased haze, as found in the 1st period of the project. In order to fulfill the light weight/high VLT requirements new glass flakes with a refractive index much closer to the PVB+softener polymer were developed and manufactured in a mini-plant at UBT.

The required refractive index matching is 0.00x, for the optimized PVB-softener polymer matrix a range from η_D = 1,493 for softener free PVB to η_D = 1,483 for PVB with 25 wt% softener glass is required. New glass compositions were developed and processed into flakes in order to enable accurate adjustment of the refractive index for the polymer matrix and the strengthening particles.

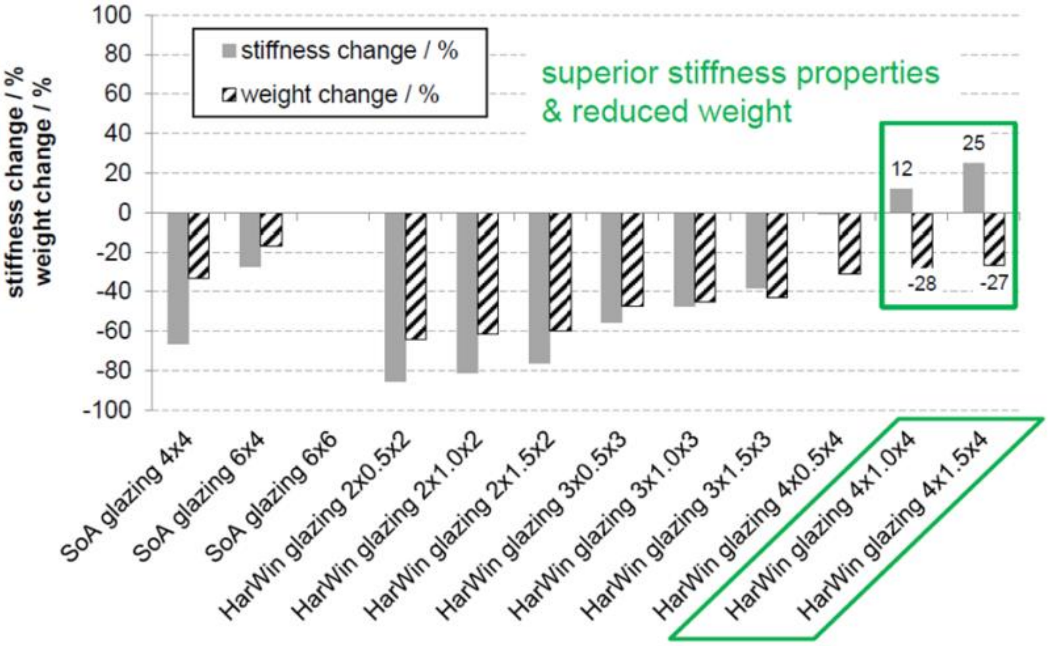


Figure 2.1-4.: Comparison of the results of simultaneous improvement of mechanical properties and weight reduction for HarWin glazing panes relative to state of the art 6x6 mm² laminated glazing. Description: 4x0.5x4 means two 4 mm glass panes laminated with 0.5 mm of softener containing PVB-glass-flake composite.

For optimized mechanical, acoustic and visible light transmission properties of HarWin glazing as polymer matrix Poly-Vinyl-Butyral, PVB with softeners and as strengthening additive new glass flakes with improved refractive index matching were utilized.

Thermal and VLT properties of polymer-glass composites and of laminate glazing

Simulation of thermal properties of the PVB/glass flake composite has been refined as compared to results reported in D 1.9 in the 1st report. The aim of the advanced study is to investigate the theoretical limit of heat conductivity of the polymer-glass composites. Details are described in D1.12. The alignment of the glass flakes inside the PVB matrix has been modified such as to arrive at a “stacked” distribution of rectangular glass flakes (20x20x1 μm^3). The thermal conductivity of the particles can be varied from extremely low, like “vacuum” to values characteristic for glass. This simulation enables calculation of a “representative” heat conductivity of the polymer-glass flake composite as a function of volume percentage and heat conductivity of the glass particles.

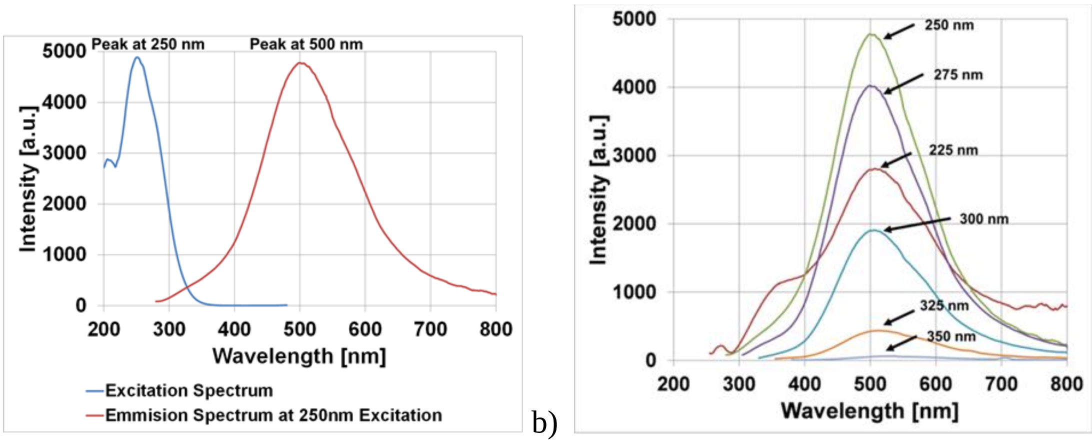
A significant decrease of the composite thermal conductivity would be achieved with glass flakes of $\lambda_{Flake} \ll 0.225$ W/m·K, the heat conductivity of the PVB matrix. In general for further material development the thermal conductivity of the reinforcing inclusions should be lower that the conductivity of the matrix to achieve significant reduction of thermal conductivity for the interlayer composite.

Concluding remarks

An excellent VLT for the composite and composite laminated glazing of >90% is achieved while the haze of the laminated glazing was reduced below 2% with further potential depending on the quality of the glass flakes. Stiffness of the interlayer can be adjusted between 10 MPa and 10 GPa depending on the desired function (weight, security, sound). The U-value could not be significantly reduced when using a single laminate setting. To meet the U value goal of the call, multi-glazing was used (see WP2).

Energy harvesting by Luminescent Down Conversion requires a new glass, based on a zinc borate and doped with metal-ions to achieve luminescent properties. Small flat glass samples as well as glass flakes were manufactured from this glass and investigated for their optical and luminescent properties by using UV-Vis-spectrometers with different set-ups. The maximum excitation wavelength is found at 250 nm, it corresponds to a maximum emission at 501 nm. The photon efficiency of a 1-2 mm thick glass pane reaches 30% as shown in Figure 2.1-5.

a)



b)

Figure 2.1-5.: LDC glass optical properties of 1-2 mm thick glazing, a) excitation and emission spectrum, b) emission photo efficiency at different wavelengths.

Scale-up and manufacturing of specialized HarWin glazing and data base for LCEA of HarWin glazing

The slurry based process used for lab-scale sample preparation of the PVB-glass flake composite cannot be easily scaled to large volumes, as drying, blade casting, tumble mixing, etc. are not used as industrial processes for laminate foils. Commercially, these foils would be manufactured by extrusion. Lab scale extrusion was performed with a single screw extruder available at WUT, using different glass flakes (Eckart and UBT) and PVB (B75H, B30H) with and without softener as polymer matrix. It was found that using Eckart flakes with different amount of softener, the resulting foils were clear, with comparable optical properties (haze, VLT) to samples created through the slurry based method. Using the glass flakes produced at UBT with matched refractive index, the resulting PVB-glass composites were dark and brittle and could not be further processed into foils. Several parameter variations were tested including PVB with different chain length, softener content and processing temperature (T= 170°C – 200°C) without success.

The inability to manufacture larger quantities of extruded polymer-glass composite foils caused a delay in several Deliverables for which this material was required because the composites had to be processed via the time consuming slurry process. Manufacturing of thick interlayers is particularly difficult with this processing variant.

WP 2 Added functionality for solar energy harvesting

Summary

In order to enable solar energy harvesting the glazing must have a high Visible Light Transmission and as low as possible heat gain. This is achieved with Anti-Reflective (AR) and low emissivity, low E coatings applied on the individual panes of a multiple glazing. Detailed investigations were performed on laminated glazing as compared to state of the art multiple glazing to establish the optimized arrangement of the different coatings to thin glass laminated panes reinforced with polymer-glass composite interlayers and other glass panes arranged within the multiple glazing.

Application of porous SiO_2 coatings on the outer glass pane of the laminated glazing yields a VLT increase in the range of 4-6%, depending upon the cleanliness of the lamination process while low E coatings cause a significant reduction of VLT. In multiple glazings low E coatings are needed to reduce the thermal gain and enable a small U-value. It is therefore required to combine different coatings and use additional principles of energy harvesting to develop smart windows with reduced energy over the life cycle.

The goal of solar energy harvesting in HarWin is based on a thermal and on a lighting effect. Thermal energy is stored and released with the help of Phase Changing Materials, PCM, which are encapsulated in porous glass particles and embedded with the help of polymers in laminated glazing.

The lighting effect is based on Luminescent Down Conversion, the absorption of high energy photons from the UV part of sun radiation by a special glass which converts the absorbed UV light into the visible wavelength range and emits radiation at ~500 nm.

New low U-value glazing concept

In the 1st periodic report it was already stated not to follow the idea of a perfect insulating glass-flake surface structure, which minimizes the heat transfer at the interface glass-flake / PVB interlayer – as suggested by the results of preliminary modelling - because of the negative influence on the VLT and the physical limit to achieve in a pure laminate structure the U-value requirements of U_G = 0.5 W/m^2K (see WP1 task 1.1).

Therefore development work in the 2nd period was focused on the alternative path of a multiple glazing. In this design the front glass component is a light weight thin glass laminate with glass-flake containing PVB interlayer, which must serve for the mechanical stability. Further 1 or 2 low-E coated thin glass components will be added, which in combination with the gas filling in the gaps between will serve for a minimum U_G-value.

Integration of known AR- and low e-coatings into laminate glazing is continued with the aim to scale-up the multifunctional laminated glass developed on lab scale and in particular concentrate on lamination of thin glass panes with polymer-glass flake interlayer.
Once the process is established evaluation of cost and embodied energy parameters for different glazing setups has to be performed based on experimental data obtained with the specialized HarWin glazing variants.

While in a pure laminate structure integrated low-E coatings give no benefit with respect to optical and thermal properties such coatings are very useful to reduce U value of multiple glazing.transfer.

In multiple glazing heat transfer is dominated by thermal radiation and the emissivity of the glazing surface will strongly influence the thermal insulation indicated by the U-value, as shown in Table 2.2.-1..

Double glazing design:

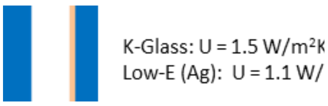


Table 2.2-1.: U-value of different double glazing designs

Design	Emissivity	calculated U-value
Glass / Glass	$\varepsilon_o = 0.84$ - $\varepsilon_i = 0.84$	2.66 W/m^2K
Glass / K-Glass	$\varepsilon_o = 0.84$ - $\varepsilon_i = 0.15$	1.45 W/m^2K
K-Glass / K-Glass	$\varepsilon_o = 0.15$ - $\varepsilon_i = 0.15$	1.24 W/m^2K
Glass / Low-E Glass	$\varepsilon_o = 0.84$ - $\varepsilon_i = 0.04$	1.10 W/m^2K
Low-E Glass / Low-E Glass	$\varepsilon_o = 0.04$ - $\varepsilon_i = 0.04$	1.08 W/m^2K

The different double glazing designs in Table 2.2.-1 demonstrate the influence of the emissivity of the glazing surface on the achievable U-value. Depending on the low-E quality of the glass component the U-value is decreased by more than a factor of 2 starting from a simple glass/glass design to a double glazing structure with a high quality silver low-E coated component. The basic thermal properties represented by the U-value of the glazing are summarized in Table 2.2.-2. Whereas a single thin glass pane with low-E coating has a U-value as high as U_G 0 5.8 W/m^2K, the multiple glazing designs show distinctly reduced values of 1.1 W/m2K for double glazing and 0.5 W/m^2K for triple glazing design of final demonstrator III; all values were calculated for an optimized glazing structure with Ar filling.

	low-E glass (2 mm low iron)	Double glazing (demonstrator I) 1 x low-E glass	Triple glazing (demonstrator II) 2 x low-E glass
U-value	**5.8 W/m^2K**	**1.1 W/m^2K**	**0.5 W/m^2K**

Table 2.2.-2.: U-value of low-E coated thin glass in different structure: single pane, double and triple glazing

In the multiple glazing designs selected for the HarWin Demonstrators VLT and energy transmission are strongly influenced by the implemented low-E coated components.

The optical properties of integrated low-E coated thin glasses are also dominated by the applied low E coatings, as shown in Figure 2.2.-1.

The properties of the Demonstrator glazing over the full wave length range are shown in Table 2.2-3. The energy transmission is higher in double than in triple glazing mainly because of the higher UV transmission.

The energy harvesting concept of HarWin includes use of Luminescent Down Conversion glazing. As described in WP 1, the LDC glass developed in HarWin absorbs UV radiation and emits light at 500 nm wave length with 30% photonic conversion. If in future this LDC can be manufactured on large scale the energy transmission of the glazing could be strongly reduced due to UV absorption by the LDC glazing.

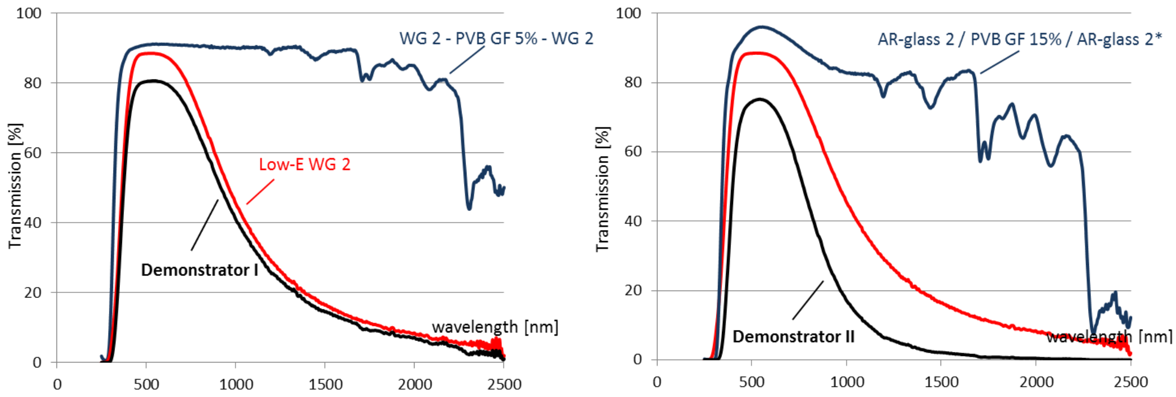


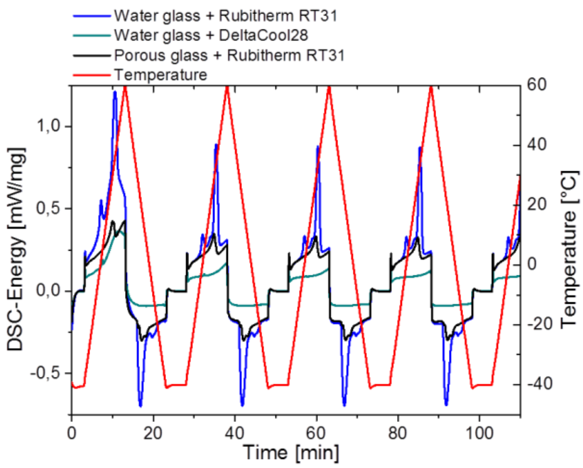
Figure 2.2.-1.: Transmission spectra of double (Demonstrator I) and triple glazing (Demonstrator II)

calculated values	Demonstrator I (double glazing)	Demonstrator II (triple glazing)
UV transmission T_{UV}	30.2 %	8.8 %
Light transmission T_{VIS}	80.3 %	74.3%
Energy transmission T_E	57.2 %	35.5%

Table 2.2-3.: VLT and energy transmission for demonstrator I (double glazing with 1 low-E glass) and demonstrator II (triple glazing with 2 low-E components)

Added functionality with Phase Changing Materials, PCM

Inorganic as well as organic PCM could be incorporated either into porous glass flakes or porous sodium silicate glass to yield encapsulated PCM which can be used as additional thermal mass in smart windows. An autoclaving process is necessary when using porous glass flakes as matrix material which makes manufacturing of such an additive more difficult. The thermal mass effects were investigated by Differential Thermal Analysis, DTA. Structural changes occur with the inorganic PCM upon incorporation into a porous matrix therefore for HarWin Demonstrator glazing organic PCM is utilized. In Figure 2.2-2 the different PCM variants and encapsulations are compared with respect to thermal response and microstructure of encapsulating materials. Various small-part prototypes of HarWin PCM containing laminate glazing were produced. A measurement procedure was developed to determine the dynamic time response of prototypes to temperature changes, revealing the influence of thermal mass. Lamination of glass panes with the encapsulated PCM has been achieved for PCM containing porous glass flakes / porous sodium silicate glass either with a polymer Elastosil matrix or with PVB foils.

a) 

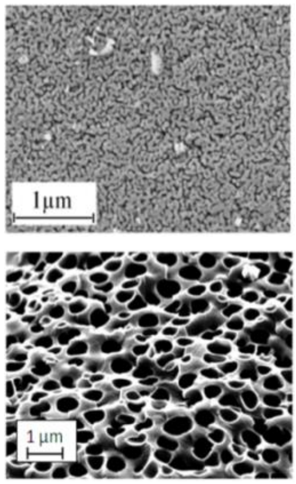
b) 

Figure 2.2-2.: a)1 DSC-measurement of samples with different combinations of PCM (organic and inorganic) and different porous materials (Vycor-glass and sodium silicate particles), b)microstructure of Vycor (top) porous glass and sodium silicate porous glass (bottom)

A 0.25 m^2 framed PCM - sodium silicate - Elastosil prototype was produced to demonstrate the basic feasibility, images of the PCM glazing with different frames are shown in Figure 2.2-3a-c. This prototype was constructed in close cooperation between FhG ISC and UBT. This collaboration includes the capabilities to produce PCM-infiltrated porous glass flakes in large enough quantities and identification of PCMs compatible with a lamination process which requires 130 °C processing temperature.

Figure 2.2-3.: PCM-Demonstrators 0.25 m² arera, without and with wooden frames.

Future development should concentrate on increase of the PCM quantity within the interlayer of the glazing. The system PCM – sodium silicate seems to be the most promising system in this respect.

WP 3 Laminated composite glazing components with added functionality

Summary

Based on material development in WP 1, WP2 for glazing and WP4 for frame in WP 3 demonstrator-size glazing components were manufactured along with demonstrator size light weight frame. The glazing area is 500x500 mm, the total area of glazing and frame is 600x600 mm.

Weight reduction of almost 50% as compared to state of the art triple glazing is achieved by reducing the thickness of the glass panes and increasing the stiffness of the glazing by lamination of thin glass panes with glass particle reinforced polymer interlayers.

The selection of individual glass pane thickness, arrangement of laminated and single panes of different thickness as well as of the width of gas filled gap was guided by macro-simulation to arrive at as low as possible U-value, highest possible VLT and lowest possible weight.

The required high visible light transmission (VLT) is achieved by combined effect of high visible light transparency of the polymer-glass composite foils, AR-coatings at the outer glass pane, ultra-white glass panes and low haze.

Integration of passive solar energy harvesting by means of PCM latent heat storage at daytime and release at night has been made possible with organic PCM-materials. For implementation of PCM into laminate glazing restrictions with respect to choice of PCM material and polymer interlayers were identified. Also, unexpected physical effects were discovered upon infiltration of PCM into porous glass particles, the phase transformation was retarded in the nano-scaled pores of the porous glass and the composition of the inorganic PCM was irreversible changed upon infiltration of the PVM into the porous glass particles in an autoclave process. A

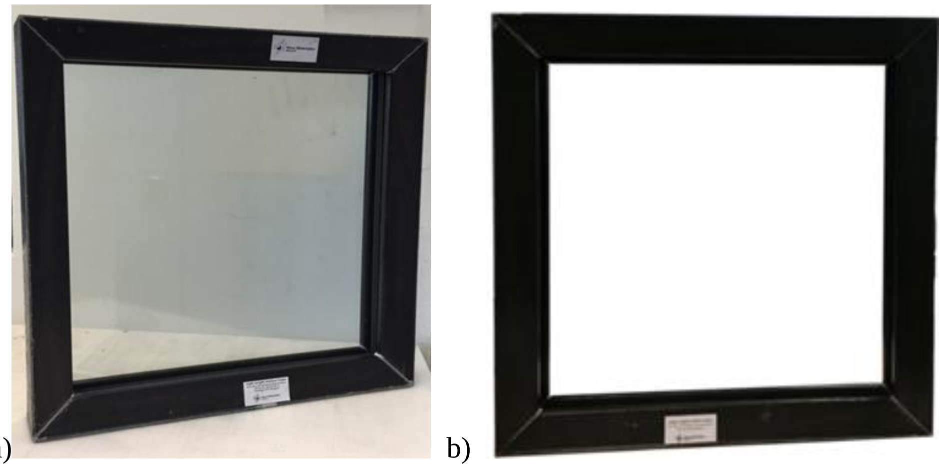
As feasible solution organic PCM incorporated in porous glass and laminated with different polymers between panes has been identified and processed in Demonstrator size of 500x500 mm. The constraints of specialized glazing and PCM-containing glazing were analyzed for different types of buildings and environments.

Integration of frame and glazing

To enable integration of the laminate glazing with the light weight frame the design of the frame had to be adapted to the manufacturing process. The process requires a special mold, which provides a fixed cavity size for mounting of glazing. This turned out to be a serious drawback for optimization of U-value of multiple glazing because a fixed size of a notch for mounting the glazing had to be chosen. In order to progress with the integration of laminate glazing and light weight frame a compromise was accepted in terms of U-value which is negatively influenced by a limited width of the notch. In addition extended modelling work was performed to improve the construction of the frame and evaluate the stress concentration in the joining region. The glazing is glued with the frame – the adhesion strength of this joint was investigated experimentally by appropriate testing on model samples.

GFRP – Frame for 3rd stage demonstrator – design status and performance

The focus of the 3rd stage demonstrator was to manufacture a full-sized prototype lightweight frame and the integration with glazing. Apart from that, the mechanical performance of the window frame was to be determined. The full-size demonstrators are shown in Figure 2.3-1. The components used were developed as a part of the deliverable D3.7.



a) b)

Figure 2.3-1: Full-sized demonstrators: a) low U, high VLT light-weight laminate multiple glazing in light weight frame, b) PCM-glazing in light weight frame.

A complete mechanical and thermal testing of the demonstrators could not be performed following building standard procedures because of limited size of the windows (sash) elements. But as shown in Figure 2.3-2 the ball drop test used to characterize the safety glass properties of laminate glazing could be executed to decide which thickness and composition of the reinforcing polymer-glass flake interlayer is required to achieve the desired safety behaviour. Only the PVB-28% softener interlayer provides safety-glass behaviour.

Figure 2.-2.: Results of ball drop testing for 3 different glazing variants with (from left to right): PVB-28% softener; PVB-GF21% softener; softener-free PVB.

The design of the glazing variants is shown in Table 2.3-1.

Table 2.3-1.: Design of glazing for ball-drop testing.

Standard PVB with 28% softener	PVB-GF 15% with 21% softener	Softener free PVB / Mowital
	[interlayer thickness: result ball drop test]	
glass 2 / interlayer / glass 2		
d = 0.38 mm: critical (small crack)		d = 0.25: failed
d = 0.76: o.k.		d = 0.75: failed
d = 1.52: o.k.		DEM II: d = 0.75-GF 15%: failed
glass 1.5 / interlayer / glass 1.5		
d = 1.52: o.k.	DEM III: d = 0.50-GF 15%: failed	d = 4.50: failed

In order to achieve safety glass characteristics for glazing with PVB-GF-softener composition a thick interlayer – in the order of magnitude of 1.5 mm – would be required. Due to processing method limitations such thick glass particle reinforced PVB interlayers were not available in the duration of the project.

WP 4 Light weight frame and glazing

Summary

In WP 4 the material development results from WP1 and WP 2 as well as processing concepts developed in these workpackages were taken further towards development of manufacturing methods for different glazing components, light weight polymer-glass composite frames and demonstrators which assembly both types of newly developed components.

Data on mechanical and thermal properties of the glazing and frame components were collected from experimental investigation on lab-scale samples processed with the same methods which were also applied for manufacturing of the Demonstrators. These data were used for macroscopic simulation performed with the aim to support and improve the final design of the Demonstrators. Also, component and processing data were provided to further develop the new LCEA toll for windows established by JRC.

With respect to frame improvement experimental results revealed the optimum sandwich structure to be composed of Expanded Polypropylene -GF reinforced tapes with final specific density of 120 kg/m³, (EPP 120) and a Polyethylene-Terephtalt (PET) as foam core. For these structures a very high adhesive strength was found along with a low thermal conductivity and a high flexural stiffness. Based on LCEA results a “monomaterial” sandwich structure is to be preferred, made of Polypropylene matrix polymers.

Modeling of composite frame integrated with polymer-composite glazing was performed based on measured mechanical data, and the potential for implementation of micro-mechanical models was tested. Results of LCE analysis of the embodied energy of materials used were implemented into the optimization of frame and glazing integration with respect to material consumption needed to achieve the required mechanical performance. The detailed results of LCEA and added value analysis are reported in WP 5. The design of the frame and glazing was modified to improve thermal resistance and overcome restrictions from a certain manufacturing technology. In order to improve the thermal insulation of the glazing, a gas filled gap like in all multiple glazings is also applied in HarWin glazing structure.

Basalt glass fibers for reinforced frame

In the 2nd period the concept of new sizing developed by Isomatex and jointly tested by Isomatex and WUT was implemented into fiber manufacturing. Table 2.4-1 gives an overview of developed formulas used for fibres impregnation.

From practical point of view, the glass fibers (including basalt fibres) can be applied for composites preparation as:

- chopped fibres that are compounded with the pure PP or PP/PBT polymer blend, then extruded as tapes with short length reinforcement;
- continuous fibers that can be used in knitted fabrics, or any other structural reinforcement, including unidirectionally reinforced (UD)-tape.

For comparison with the commercially available GF-fiber reinforced tapes used in HarWin UD-tapes would be required. Unfortunately the availability of sized knitted Basalt Glass fibers was limited, it was therefore decided to use chopped BG-fibers which could be processed with the available equipment and supplied in the desired amount and time by Isomatex. The results of tensile and flexural properties improvement are presented in Figure 2.4-2. More detailed are described in the Deliverables. Tensile and flexural properties are increasing with growing amount of basalt fiber.

Table 2.4-1.: Summary of developed different sizing for basalt fibres

Sizing	Ref.	Compatibility	Sizing key factors
EPOXY-	IS28	Thermosets	Reactivity, Strands integrity,..
TEXTILE	IS29	PU, PEs	Textile machinery easiness
THERMOPLAST (1st gen)	IS38	PA and PBT	Thermal stability
THERMOPLAST (2nd gen)	IS 43	PA and PBT	Flexibility
PP (1st gen)	IS44	PP	Balance of MW / grafting Drying & Migration thermal treatment
NEW : PP&PBT (1st gen)	IS47	PP and PBT	Addition of PU, chemical anchor Optimized Sizing solid cont. Optimized drying

The most promising sizing was IS47 (modification of IS44) since it contained components compatible with both PP and PBT polymers used for light weight frame. Summary of mechanical properties of developed fibers is presented in Figure 2.4-1.

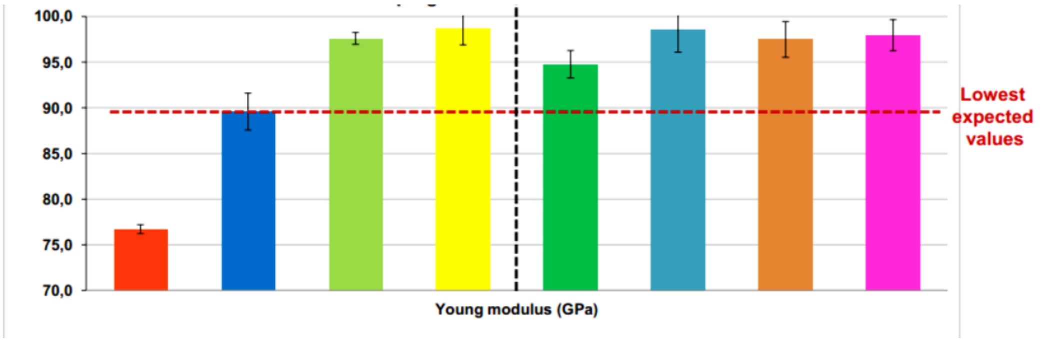


Figure 2.4-1.: Summary of mechanical properties of basalt fibers modified with different sizing compositions.

Development and manufacturing of fiber reinforced light weight frame

As best processing method for the new polymer foam core-GF reinforced skin window frame a Compression Moulded Compound has been selected. The GF reinforced material is used as a tape. 2D sandwich panels were manufactured by compression molding using commercially available thermoplastic endless fiber reinforced UD-tapes for face sheets, to provide tailored thickness and fiber orientation in the face sheets. Specimens for mechanical and thermal measurements were prepared by water jet cutting. The bonding strength between face sheets and foam core was measured in compliance to DIN EN ISO 4624. It can be seen from Figure 2.4-5 that the fracture behavior was significantly influenced by material properties of the foam core. EPP showed a ductile failure while PVC a brittle one.

Thermal and mechanical performance of light weight frame

Thermal conductivity measurements are necessary to calculate the U-value of the sandwich structure. For comparison the tapes and foams were also thermally characterized. The measurements were carried out with the Lasercomb Fox 50 in compliance with DIN EN 52612-2, the results are shown in Figure 2.4-2.

It is evident that the thermal conductivity of the sandwich structure is slightly higher as compared to the polymer foam, because of the high thermal conductivity of glass fibers, which have 10x the thermal conductivity of polymer foams. But this effect is negligible in view of the absolute value of 0.050 W/mK and an increase of 0.01-0.02 due to fiber reinforcement. Some aspects of mechanical performance should also be taken into account. With increasing foam proportion both the mechanical properties and the U-value decrease. But even if the foam core has a share of 99% - in this case the skin layers are 1 mm thick -the flexural stiffness of the sandwich structure is still much higher as compared to a state of the art PVC-frame.

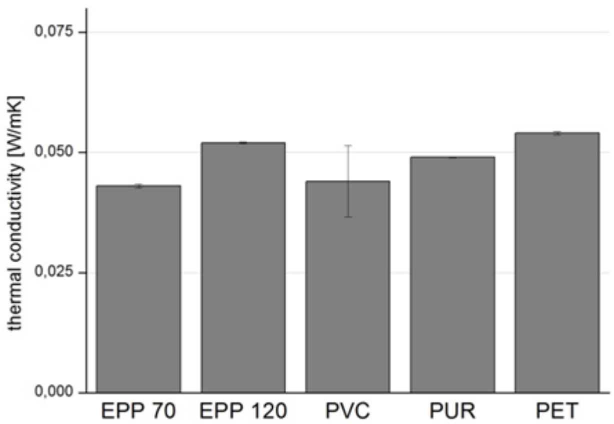


Figure 2.4-82: Thermal conductivity of the polymer foam materials (PET, PUR, PVC) and in comparison the GF reinforced sandwich structures (EPP 70, EPP 120).

A calculated U-value for EPP-foam sandwich of 60mm thickness with a GF reinforced PP-tape reaches a U value 0.7 W/m²K. Such a low U value represents only ~50 % of U-values reported for different state of the art frame materials. Consequently, it can be stated that the light weight frame has the potential for a slim window sandwich structure frame with extraordinary positive thermal properties.

One of the objectives of Harwin for the development of a new light weight frame is to have full recycleability of the window frame by insuring "mono-material" composition. Because of good recycle ability the core and the tape material should therefore be based on Polypropylene, PP. therefore EPP 120 kg/m³ has been selected for further examinations.

The thermal and mechanical properties of the different sandwich materials available are collected in Table 2.4-2.

	PP-GF60 / EPP 70	**PP-GF60 / EPP 120**	**PP-GF60 / PVC (reference)**
thermal conductivity W/mK	0.043	0.053	0.044
U-value* W/m²K	0.57	1.1 0.68	1.2 0.59
bending stiffness Nm²	50.7	1.3 46.52	1.4 20.01

* frame thickness 70 mm

Table 2.4-2.: Thermal and mechanical properties of sandwich materials investigated for their use a new light weight window frame.

WP 5 Modeling of glazing constraints, component performance and building integration

Summary

In the first half of the project the virtual test environment using Dynamic Simulation Modeling (DSM) method based on IES <Virtual Environment> software has been used to define different building types, climate zones and characteristic features of new as well as old buildings to establish a ranking list of building applications for the newly developed HarWin windows. In the *second period* of the project modelling of building performance with specialized HarWin glazing and frame has been performed and compared against a reference case with state of the art multiple pane windows.

Experimental data collected from the 1st and 2nd Demonstrator glazing and frame were implemented into the existing <Virtual Environment> software with the help of a new tool. Simulation of different design variants – specialized pane and new light weight frame has been performed to establish a ranking list of building applications.

24 baseline scenario models are presented in D5.5 i.e. 3 building types x 4 climate zones x 2 construction scenarios per building type. In addition to the 24 baseline scenario models a further 6 models per scenario model have been created representing the following HarWin demonstrators: 1) Glazing 1 and frame 1, 2) Glazing 1 and frame 2, 3) Glazing 2 and frame 1, 4) Glazing 2 and frame 2, 5) Glazing 3 and frame 1, 6) Glazing 3 and frame 2. Each demonstrator combination of glazing and frame creates a new modelling scenario, a total of 168 modelling scenarios and variants were simulated.

With respect to holistic analysis a "Life Cycle Environmental Assessment (LCEA) HarWin tool" has been created with the aim of helping the HarWin partners to address the environmental loads of the innovative glazing and framing systems during the different stages of the design process.

The tool has been thought to help with the identification of the most influencing parameters under the environmental point of view. The tool is presented in the format of an Microsoft (MS) Excel tool (see M20). The tool is a simplified Life Cycle Assessment (LCA) tool streamlined to HarWin windows. These features allow manipulation of the tool by non LCA experts (i.e. partners of the consortium) so that Research and Development (R&D) decisions can be made not only on technical and functional grounds but also on environmental grounds. The tool is made by 6 worksheets:

i. LCEA of basalt fibre reinforced polymer (BFRP) frame of HarWin window;
ii. LCEA of laminated glass pane of HarWin window;
iii. LCEA of the whole HarWin window;
iv. Environmental impact of HarWin window design options in the context of the environmental impact of the state of the art (SoA) windows;
v. Environmental impact of transports for the HarWin windows with regard to the impact of their production according with different building types;

Environmental impact of the use phase of HarWin window is analyzed in the context of the impact of the state of the art (SoA) windows, evaluated through energy simulations run for 32 scenarios (different building types, building age, location, energy mix).

Each sheet has been compiled with the contribution of the whole design team which sent primary data on materials and processes. These data were extremely useful to refine and integrate the generic data available from the commercial databases.

Another key goal of WP 5 is the analysis of incorporation of transparent thermal mass in the form of phase change material (PCM) into windows. In order to guide the research and development process and determine the magnitude of potential benefits from achieving this goal, it was originally planned to accurately model the HarWin PCM window pane within a dynamic building simulation tool. Because of specific features of the VE software it was agreed in an Amendment to split this task into two activities:

i. the <VE> building simulation tool is used for static simulation, performe by IES
ii. In addition the software IDA Indoor Climate and Energy is used for dynamic simulation by GlassX

The "LCEA HarWin tool" will allow incorporation of simulation results coming from both VE and IDA Indoor Climate and Energy software simulations, to evaluate environmental sustainability of the newly developed "HarWin" windows with an holistic approach.

IES have undertaken software development work to implement the 'specialized pane' feature into the VE software. The term 'specialized' pane is used in this context to describe whole composite laminated panes consisting of coatings, glass panes and polymer glass flake (GF) composites (not including PCM). The modelling approach adopted by IES in consultation with HarWin partners is shown in Figure 5.1. The approach is based on a representation of aggregated properties of the pane as a whole, rather than an attempt to model the complex interactions of its constituents. This approach has been supported by appropriate experimental data from the Demonstrator I and II, and two frame variants: Frame 1 with commercial glass fiber reinforced polymer tape as cover layer and Frame 2, with Basal Glass (BG) reinforced polymer tape as cover layer.

One feature of energy harvesting with the help of a window in the HarWin project is based on the introduction of transparent thermal mass into windows through the use of transparently encapsulated phase change materials (PCM). Potential benefits of an increased thermal mass of transparent façade parts are a lower building energy demands for heating and cooling, increased daylight utilization and better indoor temperature equilibration. By increasing user thermal comfort and building energy efficiency, the use of HarWin glazing could therefore provide benefits to all relevant stakeholders at once. In order to determine the magnitude of such benefits and guide the development of HarWin PCM panes and the corresponding encapsulation accurate simulation of the effect of PCM windows on building energy performance plays a major role. The system components which have to be taken into account include a large number of components and effects which constantly influence each other, such as solar gains, thermal mass, HVAC system, and occupant behaviour. The magnitude of PCM effects will depend heavily on its role in these interactions and on the ability to positively influence the use and control of active building components. While simple back-of-the-envelope calculations can inform and guide the preliminary work on this topic – and have subsequently been conducted and used within the first part of the project – only a dynamic building simulation can capture all these interactions and determine the effects of PCM inclusion with the required level of accuracy. Using the IDA software the energy savings potential of PCM in windows could be quantitatively analyzed.

The savings potential of PCM depends on whether heating or cooling energy is in focus. For cooling energy even a thin HarWin PCM pane (1 mm interlayer) represents a sufficient amount of thermal mass for measurable energy savings. Thicker layers allow more significant cooling energy savings to be achieved providing that sufficient night cooling is insured. Heating energy savings are only observed with thick layers in the office case, in the other cases the HarWin PCM panes lead to increased energy demands.

The original description of work foresaw the integration of this work package into existing <VE> software of the partner IES as part of Task 5.2. A combination of technical constraints on behalf of IES and existing know-how on the side of the partner GlassX have led to the decision within the consortium to shift the work and the corresponding person months to GlassX. The change was agreed on in the consortium and is part of Amendment No.2 to grant agreement No. 314653 "HarWin". One possible attempt to use a combination of IES' Virtual environment together with PCM temperature and shading profiles pre-calculated in other software tools to determine the effects of PCM inclusion has been abandoned after preliminary work has revealed that this approach would be very complex and lead to low accuracies, mainly due to the challenge of bringing together pre-calculated profiles and dynamic building simulations and somehow calibrate such data. At the same time it was found that building simulation software and phase change modules already in use by GlassX could be adapted to the task, thereby allowing for the calculation of PCM effects on room and building within a single software environment. The building simulation of PCM windows has been therefore split into the two attempts: <VE> simulation as "shading effect" performed by IES and IDA ICE building simulation performed by GlassX.

Added value and life extension, example of LCC calculation

The use of durable materials in HarWin windows allows for life extension of the window components. The possible savings from the extensions of the life span of window's components can be evaluated using a Life Cycle Cost (LCC) approach. The details of the LCC analysis are described in D 5.4.

One of the most recent EU studies that looked into window prices is the JRC 'Evidence Base for Windows and Doors' study, performed in 2011-2012. It presents background information and proposes revised Green Public Procurement Criteria (GPP) criteria. According to this study, when purchasing replacement windows, cost considerations will be an important aspect. It is important to consider all life cycle costs and not just the product purchase price when making purchasing decisions. This includes purchase and all associated costs (for example, delivery, installation, commissioning), operating costs (including energy, spare/replacement parts and maintenance) and end of life costs (for example, removal and disposal). The report states that a LCC approach is important for GPP as it may help to procure products with a better environmental performance, whilst saving the money. Generally speaking, a more technically advanced window will have a greater purchasing cost, however the cost savings throughout its lifetime compared to an alternative product may be greater, and the balance between the two should be established in order to optimize payback. In order to obtain accurate outcomes from a LCC analysis, the inputs will need to be based on location and product specific information. The key parameters to consider are:

- The optimal performance of the window required in order to identify the correct products and product prices.
- Installation and maintenance costs – savings may be possible if a large number of windows are replaced at once or maintenance is dealt with as part of existing contracts.
- The actual expected lifetime of the products under consideration, taking into account factors that will affect lifetime estimates, such as climate, provision for proper maintenance.
- Location-specific rates for gas, electricity and water.
- Systems aspect such as the efficiency and type of boiler used for the heating.
- The wider building perspective and other energy performance changes that may be implemented at the same time.

The above mentioned study presented the following estimation for purchase, installation and maintenance costs: €265 as standard price for windows sized 1.2 m^2, excluding installation, assumed a 30 years lifetime. Installation was assessed to be some €100/standard window and €42 for maintenance over the product life of the average window (maintenance costs consist of window cleaning and –for wooden frames— painting costs). This results in €407 for the complete installed window. Using this purchase costs for different frame materials in Germany the cost for two scenarios are compared:

- Scenario 1: U_w = 1.3 W/(m2K) g=60% is assumed as a 'Base-case' - window;
- Scenario 2: U_w = 0.95 W/(m2K) g=60%, that represent a 'Thermal improved'- window.

The results show that window prices are particularly sensitive to window frame and that the price difference of a 'thermal improved' window is about the same, as this is mainly due to extra costs of advanced IGU. It should be noted that the final Demonstrator frame in HarWin reached an even lower U value, therefore better cost figures can be expected from further development of the new frame concept. Some scenarios were analyzed for different countries the results are shown in Figure 5-12.

- Scenarios definition:

Scenario 1	Plastic 'thermal improved'- window [LS=24 years] + Plastic 'thermal improved'- window [LS=50-24 years]
Scenario 2	Plastic 'base case' - window [LS=24 years] + Plastic 'base case' - window [LS=50-24 years]
Scenario 3	Plastic 'thermal improved'- window [extended LS=50 years]
Scenario 4	Plastic 'base case' – window [extended LS=50 years]
Scenario 5	Plastic 'base case' - window [LS=24 years] + Plastic 'thermal improved'- window [LS=50-24 years]

The extension of the operating phase of the two windows ('base-case' and 'thermal improved') offers the highest economic advantages in the climatic zone of the South ('Italy") where the economic importance of the operating phase is lower.

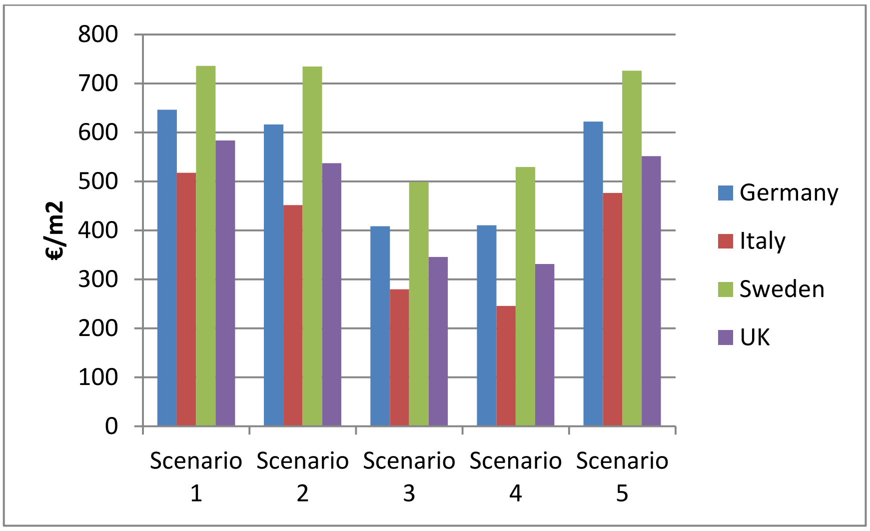


Figure 5-12.: Comparison between Life Cycle Cost (LCC) calculated for the 5 scenarios for 4 EU Countries. -Plastic window model scenario '*office building new*'.

The LCC analysis results suggest that the purchase cost can be increased (to compensate possible material and processing extra costs) from 15 to 48 % according to the different frame and IGU types, when the life time of components is extended. Nevertheless it's worth noting that this estimation it is based on the assumption that the first window is substituted, after its average operative life, by a new window that have the same cost and the same thermal performance. If we look at the scenario where the old less-advanced window is substituted by a 'thermal improved'-new window there is an extra benefit (4-6%) but in that case the savings in terms of energy consumption for heating and cooling would probably compensate the economic advantages due to life span extension.

WP 6 LCEA of windows integrated in buildings

Summary

The aim of WP 6 tasks it to define an adapted methodology to assess the environmental impacts of new multi-purpose windows along their life cycle. The environmental assessment must provide quantitative information which enables distinction between different material and construction variants of windows for different building applications. With such information those variants which will reach the project goal of 20% energy saving over the life cycle as compared to existing windows should be identified.

This is a very ambitious goal because windows are multi-component systems therefore a new methodology had to be developed to define boundary conditions and the most relevant parameters for LCE analysis.

Within the HarWin project the new LCE approach is required to characterize environmental impacts of the multi-purpose window and to identify and rank its most influencing parameters.

An important role of the new LCE methodology is to support dissemination of technical achievements of the HarWin project as well as to disseminate the LCEA tool as such and to help implement smart windows with low embodied energy into buildings to enhance the project impact.

The major achievements include a new methodology to assess the environmental impacts of new multi-purpose windows along their life cycle by provision of :

i. An adapted “LCEAHARWIN” method and “Recyclability analysis” method
ii. Datasheet for environmental primary data gathering;
iii. Feature-specific tool for the ecodesign “LCEA HarWin tool”

This new methodology is applicable as design tool for new window components – throughout the development of HarWin components the environmental analysis of possible materials and processes for polymer-glass composite glazing and glass-fibre reinforced light weight frame has been carried out to support the different phases of the design process.

The most influencing parameters for the HarWin windows were identified and ranked. The environmental analysis of product functionality integrated into buildings has been achieved in comparison to the reference case. Based on these results the potential for replacement of existing windows could be evaluated for different building types and climate zones.

The tools developed for LCA were integrated into existing databases of building simulation software, e.g., HarWin window into the <VE software> and a dataset to be published through the Life Cycle Data Network.

A very intensive Dissemination has been practiced through conference papers and posters as well as peer-reviewed journal papers.

Finally, the HarWin organizational set-up can be seen as a successful example of integration of the environmental dimension into the R&D project management.

Environmental analysis of best available glazing/frame system (reference case)

Within this topic an environmental analysis of possible materials and processes for polymer-glass composite glazing and glass-fibre reinforced light weight framing had to be performed. Based on such information the most influencing parameters, e.g. glazing material, number of layers, type of filling, frame materials, number of panes, type of glue had to be identified and ranked – here the question of parameter comparability had to be answered, e.g., weight, embodied energy, recycleability. The environmental analysis had to be updated according to the chosen window concept including detailed data concerning e.g. manufacturing processes.

In the first step modelling of the different window types is performed to define the base case scenarios. The evaluation resulted in definition of the reference case scenarios according to a panel of windows already in the market. Then the environmental impacts for the demonstrators built at different stages of the HarWin project have been evaluated within the context of the impact generated by the benchmark scenarios.

Two main objectives have been reached:

1. Evaluation of the impact of the window production and integrate the environmental aspects in the design phase of the novel product, as shown in Figure 2.6-2 by the “HarWin 1” and “HarWin 2” points

2. Identification and ranking of the most influencing parameters, like e.g., glazing material, number of layers, type of inert gas filling, frame materials, number of panes, type of glue. Details are described in D 6.2, according to different environmental categories and during different phases of the windows life. These criteria are explained in Figure 2.6-3 and 2.6-4.

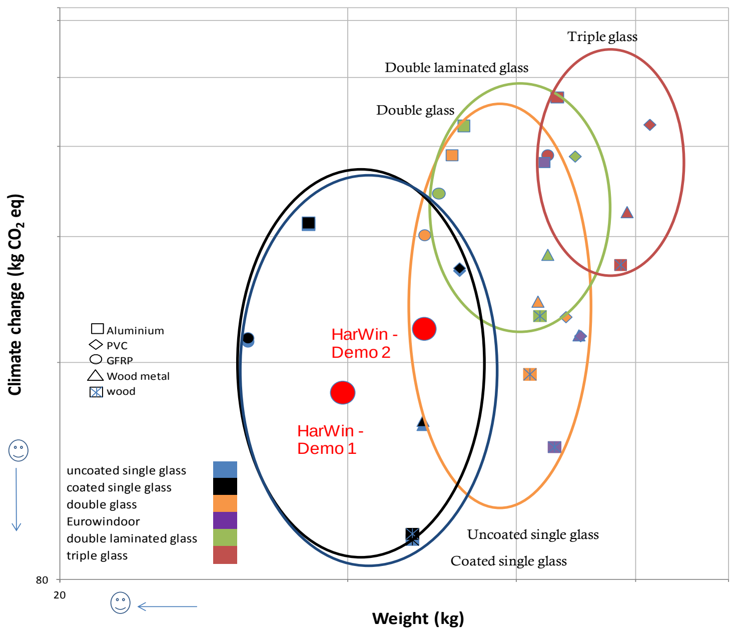


Figure 2.6-2.: Ashby–type diagram plotting climate change vs weight for 2 design options of the innovative window in comparison with the reference case scenarios

One of the objectives of the Project was to reduce the window weight by 50%. The weight reduction has been proposed to cope with the call’s aims of designing windows adapted not only for new building but also in case of refurbishment of old construction. Figure 2.6-2 shows how its weight is now comparable with weight of single glass windows.

This objective has been reached as the weight for the complete window is expected to be equal to 48 kg/FU of which 14,4 kg/FU the frame, 15,7 kg/FU the laminated innovative pane and almost 18 kg/FU the auxiliary included the glazing system (two glass panes of 2mm are added to improve the overall thermal resistance).

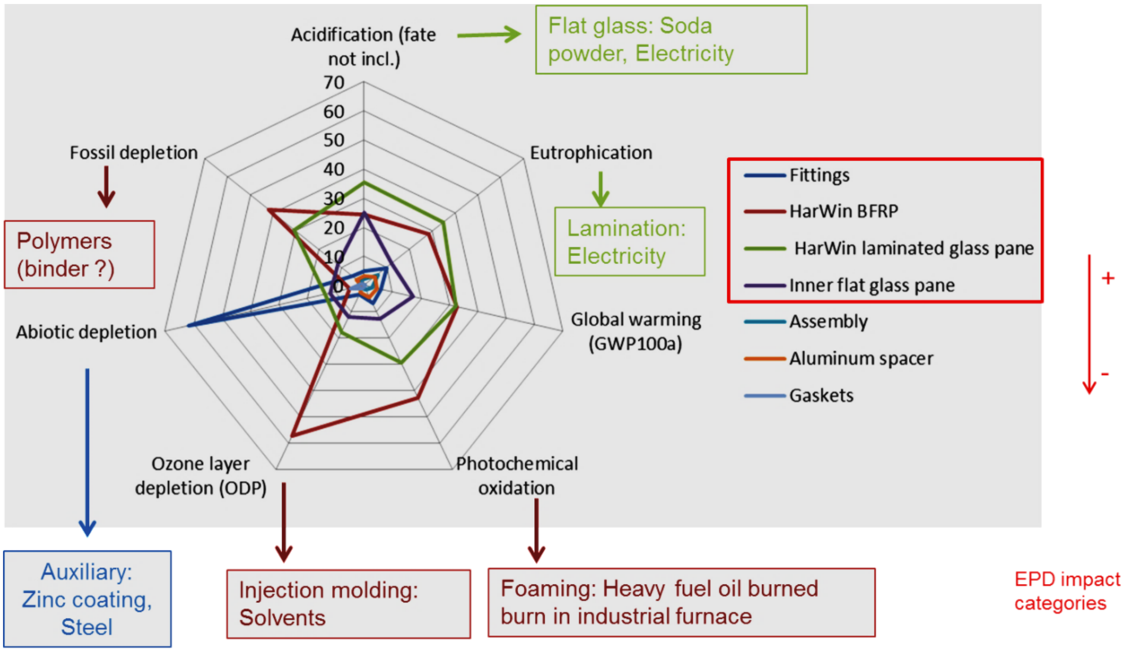


Figure 2.6-3.: Production phase. Assessment of the environmental impact of the innovative window's components according to a multi-criteria approach

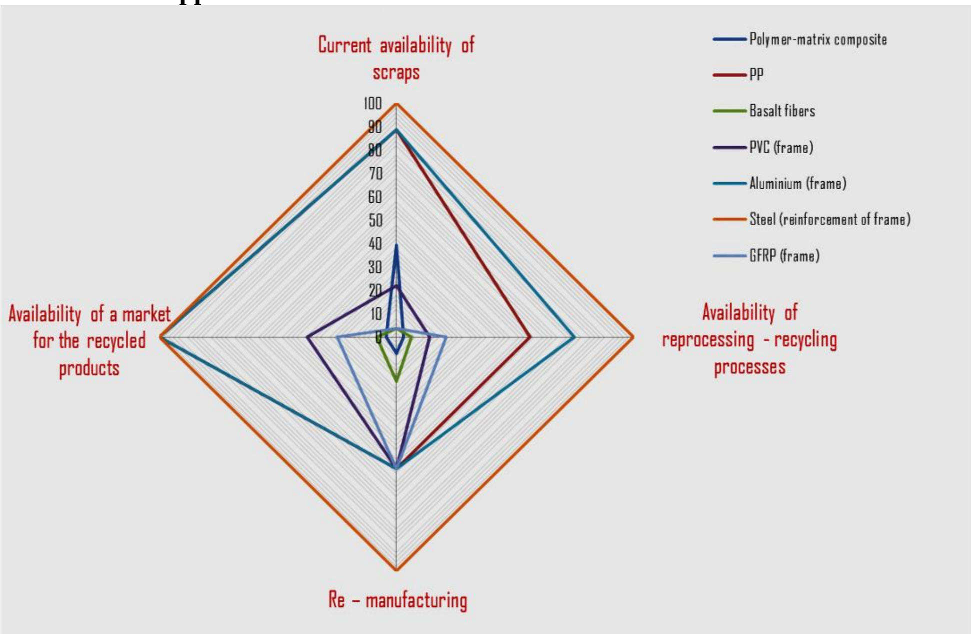


Figure 2.6-4.: End of life phase. Comparison between the recyclability rate of different frame materials according to the 4 parameters defined in the Recyclability Analysis Method.

Data for the environmental analysis of the different window options have been regularly updated (including detailed data concerning e.g. manufacturing processes).

4.1.4 Potential impact, exploitation and dissemination

The sozio-economical impact is related mainly to:

i. Increase of awareness among experts as well as the wider public of the possibilities to reduce the energy consumption of buildings with the help of new materials and new design of windows.
ii. Provide new materials and processing technologies to achieve weight reduction of windows in the order of magnitude of 50% as compared to triple glazing windows and achieve an easier installation and maintenance of windows in building
iii. Provide new methodology for LCEA of windows and window components and a foundation for guiding further development of windows components according to LCEA guidance
iv. Provide methods for cost analysis of new window components as compared to existing ones
v. Provide simulation tools for analysis of building performance and buildings constraints resulting from use of new window materials and design
vi. Enlarge the technology variants to save, store or harvest solar energy with the help of multifunctional materials for windows.

Summary on exploitation & dissemination activities

The Dissemination and Exploitation Plan was developed by BayFOR and GX based on inputs from the entire HarWin consortium. Analysis of future markets has been undertaken to support the partners during the project and to adjust the scientific and technical development according to the industrial needs and also to customer acceptance. The exploitation plan has been continuously updated. Contents were kept up to date through discussions with the project partners. The topics of Dissemination, Exploitation, project risk and IPR where discussed at the Exploitation Strategy Seminars at the M12 meeting in Brussels.

Potential future markets and products where analyzed by GX, resulting in the specification of product requirements for HarWin project results which show potential for implementation as marketable products. An example of market analysis is shown in Figure 2.7-1.

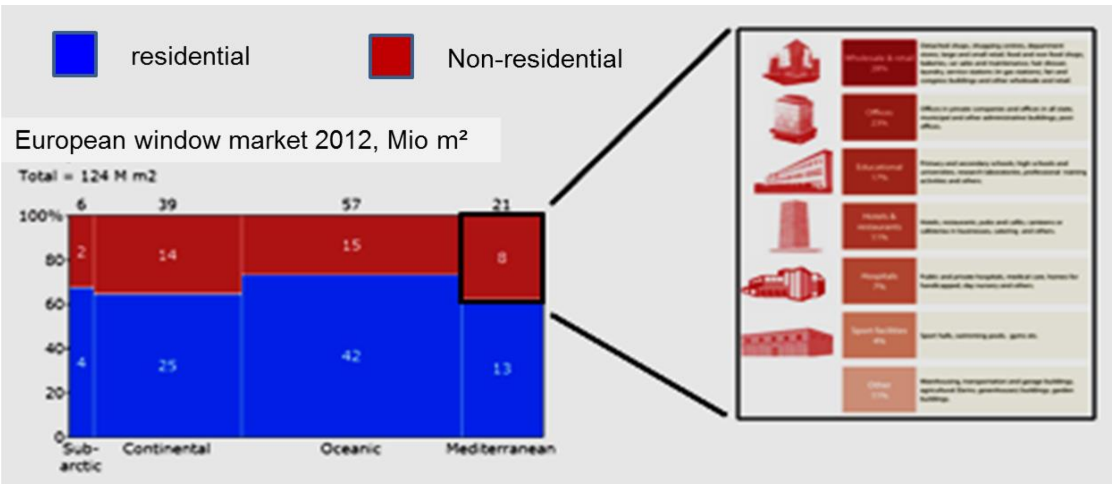


Figure 2.7-1.: HarWin market analysis by building type and climate

The analysis was based on the demands arising from regulation, industrial needs, customer acceptance and product value proposition (in comparison to current state-of-the-art products). These requirements were added as an appendix to the Dissemination and Exploitation Plan.

European-wide dissemination of the project results to the scientific community took place through conferences in Italy, Germany, Serbia, Switzerland, Spain, Poland, Greece, Latvia, Austria, to name some.

Within the World Sustainable Energy Days a special workshop and exhibition on Smart Windows has been organized together with other EU-Smart Windows projects. In addition two Dissemination and Exploitation workshops were organized: in 2013 in Szczecin (Poland) and in 2015 in Nürnberg (Germany) with strong participation from Industry.

Additional specialized workshops were organized on LCEA, in 2014 in Ispra, Italy and on Standardization within the Smart Windows workshop in Wels, Austria.

A strong contribution to Dissemination and Exploitation came through the involvement of EUROWINDOR as Industrial Advisory Board.

Through this professional network SME and large companies became aware of HarWin. The final outcomes of the project will be communicated through the newsletter of EUROWINDOR.

In addition, HarWin is participating in the AMANAC Cluster, which also intensifies the Dissemination activities beyond the lifetime of the HarWin project. A summary of major dissemination activities:

i. Home page kept up-to-date, e.g. with links to SMART WINDOWS projects
ii. Clustering and knowledge exchange among sister “SMART WINDOWS” projects EELICON, SmartBlind, MEM4WIN, WinSmart and HarWin
iii. Joint “Smart Windows” workshop at WSED in Wels, February 2015, Austria
iv. Two HarWin-workshops: in Stettin (together with WUT) and Nuremberg: fostering scientific and economical discussions between the HarWin consortium and external stakeholders
v. Fostering standardization discussions between the HarWin consortium and European and international stakeholders, e.g. EUROWINDOR
vi. Presentation of HarWin with talks at several conferences (e.g. Prague, Rosenheim, Biel, San Sebastian)
vii. Presentation of HarWin Demonstrators at several exhibitions and workshops.

4.1.5 Address of the project public website, relevant contact details.

Project website address: http://www.harwin-fp7.eu/

Coordinator-Contact: monika.willert-porada@uni-bayreuth.de

HarWin

4.2 Use and dissemination of foreground

4.2.1 Section A

The initial plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) included in Annex I has been updated according to the results achieved in HarWin until Month 36.

The consortium has a strong R&D as well as a system development competence and significant competence in LCEA and development of simulation tools. The role of consortium partners mainly involved in establishment of the plan for use and dissemination of foreground is listed below;

- GlassX – WP Leader and the main partner in terms of Exploitation (Task 7.2)
- JRC – main partner in terms of Standardization (Task 7.3)
- BayFOR – main partner in terms of Dissemination activities (Task 7.1)
- CSG (terminated by Month 16), ISMTX, IES, Fraunhofer ISC, InG – industrial (oriented) partners ensuring an efficient Exploitation of marketable product results

The main Exploitation activities consist of (a concise list is given in chapter 2.1 of this document):

- Industrially driven Exploitation activities for achievement of economic benefit
- A clause on intellectual property is included in the consortium agreement. The procedure aims to support the use of any intellectual property generated
- Establishment of a data base for LCEA of windows and glazing

The main Dissemination activities consist of:

- Submission of scientific papers at reviewed journals
- Talks on international and national conferences
- Presentation of posters, exhibits, and booths at relevant exhibitions, workshops and (inter-) national conferences
- Organization of joint activities with relevant EC-funded projects in the field of Energy-efficient Buildings
- Industrially driven dissemination activities for achievement of economic benefit

All industrial partners have expressed originally the interest to be involved in protection of the technical progress achieved in HarWin by applying for IPRs. Because of the complexity of the individual achievements it was agreed that each partner will be owner of the new developments which arise from his competence, according to the consortium agreement.

4.2.1.1 Exploitation Summary

The vision behind the HarWin project is to enable drastic reductions in European energy consumption and greenhouse gas emissions by increasing the energy efficiency of the built environment. Through the development of innovative multipurpose windows based on light weight laminated glass, major imitations of existing SoA window technologies – such as high weight, cost and complex framing constructions – could be overcome. By combining low U-values, radical weight and cost reductions and high visual light transmittance, these novel windows will enable a paradigm change in window technology.

The positive impact of utilising HarWin results for improving the energy consumption figures of buildings in Europe and achieving economic benefits will crucially depend upon the commitment of manufacturers and developers of existing window technology to pick up the results. To meet this challenge, HarWin's new material solutions were developed such as to be produced with existing technologies for laminating, coating and assembling glazing and windows.

Main levers seen as essential for laying the ground for a successful Exploitation are:

- Raising awareness for the technology among the research community in the field of energy-efficient buildings, with key industry players and with potential end-users
- Supporting the protection and use of intellectual property
- Establishing decision tools (such as life cycle environmental analysis tools, building performance calculations, product certifications) for planners and project developers
- Conducting market analysis to guide research and product development and as preparation for of a successful go-to-market

The HarWin consortium members represent the full value chain for the main target market and include industry partners specialized on basic material science, dedicated window and glazing specialists but also system integrators and building consultants. The Exploitation strategy has been updated during the course of the project based on the actual progress of the scientific work and on the input of the consortium members within a Exploitation Strategy Seminar provided by the European Service Innovation Centre (ESIC). During this seminar risks, weaknesses and conflicts of interest within the plans have been analysed and possible remedies, precautions or actions that should be taken to mitigate them were discussed. For the results of the seminar, please refer to the final report prepared by the seminar leader Mr. Peter Moran.

Actual commercial Exploitation and any concrete preparation thereof, as well as related activities (e.g. marketing) were not part of the project 314653 HarWin in general as these activities are not eligible for EU funding.

4.2.1.2 Establishment of decision tools

In order support potential end-users in integrating HarWin products in their projects, several decision tools are necessary. This includes the compilation of a life cycle environmental analysis (LCEA) methodology for the new window. This work has been performed in WP 6. As a result, an adapted new methodology for LCEA of windows has been established by JRC, an extensive database of the most relevant data has been collected from HarWin Demonstrator glazing and frame, and reference cases and an LCEA tool has been analysed to define the best application areas of the HarWin glazing and frame.

To facilitate the quantification of the HarWin value proposition and help planners and project developers to include the product in their buildings, a standard performance report and a simulation tool for building integration has been adopted to HarWin windows and will be made available for use by professional building developers and private users.

The software <VE> defines a virtual test environment where manufacturer can test their component solutions. A standard methodology is be applied to test the potential benefits and savings of the new components and to verify and quantify the component performance post installation. Benchmarks for standard building types (new and existing) and climate regions have been established.

In addition, the a checking system has been established for the <VE> software with which it is possible to test the compliance of the components with the national and regional building regulations codes..

4.2.1.3 Market analysis

To guide the development of the new product and facilitate a successful go-to-market upon completion of the development phase, user needs and potential applications will be collected throughout the project. A major contributor to market insights came through the Industrial Advisory Board, which has a deep understanding of the European window market and can bridge the gap to the window and construction industries. Furthermore, market analysis and study on possible future use cases of the project results was conducted as part of the Exploitation work package (i.e. Deliverable 7.3, Market analysis and study on a possible future use of the project results).

4.2.1.4 Demonstration activities

HarWin aims to develop a new type of multipurpose windows based on a combination of laminated composite glazing components. In order to achieve the superior performance targets for the new glazing, a multitude of functionalities has been performed. Key developments of the project are:

- Reduction of glazing weight by 50% without compromising mechanical stability and Visible Light Transmittance (VLT) by development of composite polymer-glass flake layers with high stiffness and VLT
- Production through an extension of existing lamination technology and batch wise autoclave processes (continuous lamination)
- Integration of passive solar energy harvesting by means of PCM latent heat storage
- Combination of glazing with new glass fibre frames
- Cost reduction of 15% compared to SOTA windows
- The originally anticipated extreme reduction of thermal conductivity of composite polymer-glass flake layers to achieve a U-value below 0.3 W/m²K had to be modified because of conflict with concomitant achievement of high VLT values. All criteria could be met with multiple glazing utilizing laminated thin glass panes strengthened with polymer-glass flake composite layers.

Because of the complexity of these tasks, HarWin is a high risk project. Therefore feasibility of the technical solutions based on new materials was proven with the help of Demonstrators.

To mitigate some of the risks, a modular approach has been chosen for the project in which new window materials and production processes are developed separately and then combined to form new multipurpose window components.

This does not only minimize the risk of complete project failure but gives a unique chance for transferring the gained knowledge at all levels to other applications and markets. In addition some of the new materials could be implemented into existing windows as “ad on” elements upon refurbishing buildings, e.g., existing multiple frame and pane window glazing with PCMs in thin layers between the windows or existing window frames could be replace by such containing PCM.

Within the project, the development of new materials and processes will be undertaken through several work packages:

- WP 1: Material development for light weight glazing
- WP 2: Added functionality for solar energy harvesting
- WP 4: Light weight frame and glazing

Glazing and framing components of the 1st generation were optimized towards weight reduction. The 2nd stage component aimed at achievement of low U-value and noise reduction for the glazing, whereas in the 3rd stage VLT and energy harvesting by PCM as well as light weight and low U-value of the frame were added.

4.2.1.5 Industrial Advisory Board (IAB)

The IAB consists of experts from the industry, which at this initial proposal stage are gathered by the European cluster EuroWindoor (Contact Person: Frank Koos, General Secretariat). EuroWindoor is an umbrella organization of the 4 European associations of fenestration and door sector and was created in 1999. It covers 30 national federations in Europe representing the interests of more than 50,000 companies employing around 1 million workers in Europe.

The presence of EuroWindoor in the IAB helped to raise awareness for HarWin results to the four major professional organizations in Europe, which are involved in fenestration and door sector: FAECF, FEMIB, EPW and UEMV for the three frame materials metal, wood and plastic and the infill material glass.

Because the European window industry consists mainly of small and medium sized companies (SMEs), the support of the umbrella organization is a very strong asset for successful Dissemination and Exploitation of HarWin results. Our aim is to reach the construction supply chain, the window industry supplies local construction companies with building components and is thereby a part of a local supply chain with local employment. The goal of EuroWindoor is to ensure the progress of the glazing and the window industry and to ensure high quality in products and work. This ensures the right quality for the customers and to work for a long-term efficiency for the European society.

IAB members were invited to participate in HarWin regular meetings as well as to workshops. For participation in regular meetings the Consortium gives a free of charge consultancy agreement (only travel expenses are paid) to the IAB including integrated secrecy clauses. There will be no other funding through EU project funds. In addition, to be announced representative persons of the Umbrella EuroWindoor and of its industrial members have periodically discussed the project issues with the Coordinator and Consortium members on topics like, e.g., validation of climate data used for simulation, LCEA, recycle ability of window materials, standardization.

4.2.1.6 Standardisation Aspects

Standards play a critical role in our society and by “providing agreed ways of naming, describing and specifying, measuring and testing, managing and reporting”, standards provide:

- basic support for commercialisation, markets and market development;
- a recognised means for assuring quality, safety, interoperability and reliability of products, processes and services;
- a technical basis for procurement;
- technical support for appropriate regulation

HarWin aims at developing the next generation of windows, based on new materials, in order to improve the energy efficiency of windows and buildings, when achieving also weight reduction, reduced thermal conductivity and energy consumption, reduced material usage. Considering that the windows market is huge, that windows are currently covered by several regulations and that innovative windows should present satisfactory performances not only for the aspects cited above but also for quality, safety and reliability, it can be concluded that standards can be extremely important for HarWin.

A number of existing standards that are relevant to various WPs of HarWin were identified, as presented in Table 4.2.1. Some standards (e.g. ISO 9050, EN 410) are applicable to windows and are therefore directly usable by HarWin partners. Some others (e.g. EN 15804) are applicable to building products and therefore also to windows. Some others (e.g. ISO 14040, ISO 14062) are applicable to all goods and services, including windows. Some other standards (e.g. ISO 22628, IEC/TR 62635) are applicable to other types of products/sectors but include some methodological aspects that would be relevant for some HarWin activities.

Table 4.2.1. Inventory of standards relevant for HarWin.

Reference	Title	Product covered
ISO 9050:2003	Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors	Windows
BS EN 410:2011	Glass in building. Determination of luminous and solar characteristics of glazing	
BS EN ISO 673:2011	Glass in building – Determination of thermal transmittance (U value) – Calculation method	
BS EN ISO 10077-1:2006	Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Simplified method	
BS EN ISO 10077-2:2012	Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Numerical method for frames	
EN 15804:2012	Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products	Building products
ISO 14040: 2006	Environmental management — Life cycle assessment — Principles and framework	All products and services
ISO 14044:2006	Environmental management — Life cycle assessment — Requirements and guidelines	
ISO/DTR 14062	Environmental management - Integrating environmental aspects into product design and development	
ISO 22628:2002	Road vehicles - Recyclability and recoverability - Calculation method.	Road vehicles

IEC/TR 62635	Guidelines for End of Life information provision from manufacturers and recyclers, and for recyclability rate calculation of Electrical and Electronic Equipment	Electr(on)ic equipment

HarWin partners will use as far as possible the existing standards, as the ones listed above. As standards are living documents and are regularly updated, it is possible that the findings produced by HarWin could be used by standardization committees in future revisions: it is for example possible that HarWin findings and technical characteristics of HarWin windows could have some impacts on the way to calculate thermal performances of windows or that HarWin results may demonstrate the usefulness of revising Life Cycle Environmental Assessment concerning Life Cycle Impact Assessment methods or the way to model end-of-life recycling, e.g. related to EN 15804. It is also possible that HarWin results would be the basis for new standards, like for example a method to calculate recyclability and recoverability indicators for building products (e.g. transposition of ISO 22628 to the building sector).

4.2.1.7 Homepage and Internal Communication Platform

The Homepage is kept alive by the Coordinator-Institution (U of Bayreuth, Germany) at least for 3 years after HarWin ended as project.

The domain name is www.HarWin-fp7.eu. The homepage will be maintained regularly.

The Homepage includes two independent parts:

Part one is dedicated to the broad public (which provides a general overview of the project, introduction of the project partners, published results, and so forth), and the second part is for internal consortium use only (enabling easy transfer of large amounts of information between the partners). The internal part is protected and consists of the project management platform ProjectPlace (www.projectplace.com), which will also be kept alive to enable further communication within the Consortium.

The main target of keeping the homepage alive is to increase the awareness of HarWin results to industry, science, and the open public by giving information about the project content and the consortium as well as the project outcome. It enhances thereby the project visibility in Europe and worldwide. Further, scientists and industrial stakeholder have the possibility to address their matter of interest concerning HarWin by posting their contact data and a message via the webpage to the Coordinator. In this way, new collaborations between the consortium and external partners can be initiated to ensure a quick exploitation of the project results to the market.

4.2.1.8 Consortium Agreement

The internal organization of the consortium has been signed by all partners upon decision of their prior defined Consortium Agreement (CA) which fulfils the objectives of the DoW. The CA regulates the interaction between the beneficiaries, the distribution of EC-funds and the decision making-process (e.g. voting rights). It is based on the DESCA3.0 template agreement. The CA further defines the rules for communication (internal, external) by denoting two plans, one for Dissemination and one for Exploitation. Within the Consortium Agreement the mechanisms for quality, risk and conflict-management and protection of new IPR are determined. The CA covers agreements on access rights of background and Exploitation of foreground IPR, joint ownership agreement even after the end of the funded project, and rules for defaulting partners.

4.2.1.9 Activity Groups

In order to improve the collaboration and following a suggestion of the project officer Dr. Levy, Activity Groups have been assigned to cooperate on specific topics, as shown in Table 4.2.1.2. The joint work is organized via both face to face meetings and telephone conferences. Minutes of the Activity Group meetings are regularly uploaded to ProjectPlace.

Table 4.2.1.2: Activity Groups in project HarWin

Activity Group No.	Name	Participants	Leader AG
1	GF polymer composite	ED, InG, UBT-CMP, WUT	Uwe Ott, Eckart GmbH (ED); Benedikt Scharfe, University of Bayreuth (UBT-CMP)
2	Processing laminates	CSG, InG, GX, UBT-CMP	Dr. Manfred Arnold, InGlas (InG)
3	Sizing issues	ISMTX, UBT-NMB, WUT	Prof. Mirka El Fray, West Pomeranian University of Technology (WUT)
4	Definition of building examples	InG, GX, JRC, IES	Dr. Ya Roderick, Integrated Environmental Solutions Ltd. (IES)
5	LCA (state-of-the-art, methodology)	IES, JRC	Dr. Fabrice Mathieux, Joint Research Centre of the EC, Institute for Environment and Sustainability (JRC)
6	Data on material properties and simulation	UBT-NMB, UBT-CAD, WUT, UBT-CMP, IES	Mathias Muehlbacher, University of Bayreuth-NMB (UBT-NMB); Kanat Kyrgyzbaev, University of Bayreuth (UBT-CMP)

4.2.1.10 Meetings within the Consortium, industrial visits

Besides the 6-months regular meetings listed in Table 4.2.1.3 some industrial visits have been organized:

1. To a frame producer and its window prototype manufacturing site; company Schüco, Germany
2. InGlass to see the autoclave process of lamination
3. Italian frame producer to discuss PVC recycling strategies
4. Float glass producer, company Pilkington (NSG) in Weiherhammer, Germany

Table 5: Regular biannual project meetings of HarWin

No.	Regular bi-annual meetings	Location at Partner	Project Month	Date (actual or foreseen)
1	Kick-Off	UBT – Bayreuth, Germany	2	02.10.2012

2	1st Interim Meeting	BayFOR – Munich, Germany	8	24.-25.04.2013
3	2nd Interim Meeting	Brussels, EU Commission	13	10.-11.10.2013
4	3rd Interim Meeting	WUT – Szczecin, Poland	19	27.-28..03.2014
5	4rd Interim Meeting	JRC – Ispra, Italy	25	10.-11.09.2014
6	5rd Interim Meeting	Linz, Austria	31	24.2.2015
7	Final Meeting	Brussels, European Commission	35	29./30.8.2015

4.2.1.11 List of publications

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Thermal analysis and mechanical properties of PP/PBT blends intended for modern window frames*	*Jolanta Janik, Wojciech Ignaczak, Mirosława El Fray*	*Conference Pomerania Plast 2013*	*12th June 2013*	*Proc.*	*Miedzyzdroje, Poland*	*2013*			*no*
2	*Revision of Damaged STL Data for Exchanging Geometry Information*	*C. Wehmann, M. Zimmermann F. Rieg*	*International Conference on Engineering Design (ICED) 2013*	*19.-22. August 2013*	*Proc.*	*Seoul, Korea*	*2013*			*no*
3	***"Integration of environmental aspects into R&D inter-organizational projects management: application of a life cycle-based method to the development of innovative windows"***	*C. Baldassarri, F. Mathieux, F. Ardente, C. Wehmann, K. Deese*	*Journal of Cleaner Production*	*11 September 2015*	*Elsevier Ltd.*		*2015*		*Open Access*	*yes*

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

4	*"Using life cycle based environmental assessment in developing innovative multi-functional glass-polymer windows"*	*Allacker, K., Mathieux, F., Calero, M.*	*SB13 Graz – Sustainable Building Conference 2013*		*Verlag der Technischen Universität Graz*	*Graz, Austria*	*2013*	*p.621-628*	*Open Access*	*yes*
5	*"Recyclability analysis of windows materials "*	*F. Mathieux, C. Baldassarri*	*HarWin workshop Material solution for energy efficient buildings – fenestration and façade*	*28 March 2014*		*Szczecin, Poland*	*2014*		*Link*	*yes*
6	*"LCEA method and tools for guiding the HarWin window eco-design "*	*C. Baldassarri*	*HarWin workshop Life Cycle Environmental Analysis (LCEA)*	*11 September 2014*		*Ispra, Italy*	*2014*			*no*
7	*"LCEA in R&D and research projects: EU-Initiatives and outlook. Zoom on glazing / framing"*	*F.Mathieux*	*HarWin workshop Life Cycle Enviromental Analysis (LCEA)*	*11 September 2014*		*Ispra, Italy*	*2014*			*no*
8	*"Life Cycle Data Network: an IT Infrastructure to increase LCI datasets sharing within FP7 Project consortium"*	*M. Recchioni*	*HarWin workshop Life Cycle Enviromental Analysis (LCEA)*	*11 September 2014*		*Ispra, Italy*	*2014*			*no*
9	*A life cycle method to support the design of innovative windows*	*C. Baldassarri, F.Mathieux, F. Ardente*	*SETAC 20th LCA Case Study Symposium*	*25 September 2014*	*Setac Europe vzw*	*Novi Sad, Serbia*	*2014*		*Abstract*	*yes*
10	*"Llife cycle data network as a tool to disseminate results of innovative projects"*	*C. Baldassarri, F.Mathieux*	*European Smart Windows Conference (ESWV)*	*25 February 2015*		*Wels, Austria*	*2015*			*no*
11	*"Contribution of windows to the overall environmental performances of buildings"*	*C. Baldassarri, F. Mathieux, F. Ardente,M. Oates*		*August 2015*			*2015*			*no*

12	"Recyclability analysis method: a case study of windows materials"	C. Baldassarri, F. Mathieux, F. Ardente, K. Deese, J. Beck		August 2015			2015			no
13	"LCA of HarWin windows integrated in buildings"	F. Ardente, C. Baldassarri	Exploitation HarWin Workshop	14 August 2015		Nuremberg, Germany	2015			no
14	"Porous glass-flakes for the application in multifunctional glass-polymer-windows for harvesting solar energy"	Ferdinand Somorowsky	11'th semminar porous glasses - special glasses	26 August 2015			2015			no
15	"Contribution of windows to the overall building environmental performances"	C. Baldassarri, F.Mathieux, F. Ardente, M. Oates	7th International Conference on Life Cycle Management	30 August - 2 September 2015		Bordeaux, France	2015			no
16	"Mechanical and thermal properties of PP/PBT blends compatibilized with triblock thermoplastic elastomer"	Ignaczak W., Wisniewska K., Janik J., El Fray M.	Polish Journal of Chemical Technology, 17, **3,** 78 — 83, 10.1515/pjct-2015-0053	19 September 2015	De Gruyter		2015		Open Access	yes
17	**Experimental investigation and simulation of mechanical properties in visible light transparent polymer-glass composites**	B. Scharfe; Ch. Wehmann; K. Deese, F. Rieg; and M. Willert-Porada	Advanced Engineering Materials	3-2015						
18	New Materials for Smart Windows Glazing – Optical and Mechanical Properties	M. Willert-Porada[1]*, K. Kyrgyzbaev[1], A. Saberi[1], B. Scharfe[1], Ch. Wehmann[2], F, Rieg[2], M. Arnold[3]	Special issue Journal of Facade Design and Engineering from ICAE2015		Delft University of Technology, Architecture	Nether-lands	03-2016		Open Access	yes

19	Functionalizing of glass flakes	Fraunhofer ISC	Planned							no
20	Glassflake-PCM composite materials : A New material for energy harvesting	Fraunhofer ISC	In preparation							no
21	Modelling of thermal, acoustic and mechanical properties of glass particle reinforced PVB-composites	C. Wehmann et al.	Journal of Mechanical Engineering		University of Ljubljana Faculty of Mechanical Engineering		2016			no
22	Influence of microstructure and processing conditions on Visual Light Transmission of glass particle reinforced laminate glazing	B. Scharfe, M. Willert-Porada, A. Arnold	Advanced Functional Materials				2016			
23	New Glass for Energy Harvesting via Luminescent Down Conversion Glazing	K. Kyrgyzbaev, A. Saberi, B. Scharfe, M. Willert-Porada	European Journal of Glass Science and Technology A				2016			

4.2.1.12 List of Dissemination Activities

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Kick-off*	*New Materials Bayreuth GmbH*	*HarWin Kick-off*	*02 October 2012*	*Bayreuth*	*Scientific Community*		*Germany, Finland, Belgium, Poland, UK and Switzerland*
2	*Press release*	*Bavarian Research Alliance*	*Das Fenster der Zukunft: EU-Forschungsprojekt „HarWin" revolutioniert die Energieeffizienz von Gebäuden*	*02 October 2012*	*Official homepage*	*Medias*		*Germany*
3	*Press releases*	*Bavarian Research Alliance*	*EU-Forschungsprojekt „HarWin" revolutioniert die Energieeffizienz von Gebäuden*	*03 October 2012*	*Innovations Report*	*Scientific Community, Industry*	*More than 8,200 partners*	*Germany*
4	*Press releases*	*Greentech Germany*	*Neue Leichtbaufenster sollen Wärmeleitung und Ressourcenbedarf senken*	*04 October 2012*	*Greentech Germany*	*Industry*		*Germany*
5	*Press release*	*The University of Bayreuth*	*HarWin Press release of the coordinating partner*	*05 October 2012*	*Official homepage*	*Medias*		*Germany*
6	*Press release*	*Integrated Environmental solutions Limited (IES)*	*Partner IES introduces the Project to the international public*	*October 2012*	*Official homepage*	*Medias*		*UK*
7	*Trade Fair*	*Messe Duesseldorf GmbH*	*Glasstec*	*25 October 2012*	*Düsseldorf, Germany*	*Scientific Community, Industry, Civil Society*	*Over 43,000 visitors*	*Germany*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

8	*Newsletter*	*Bavarian Research Alliance*	*Newsletter for European Universities, small-and medium sized enterprises and public administrations*	*November 2012*	*Official homepage*	*Medias*		*Germany*
9	*Press releases*	*BINE Informationsdienst*	*Fenster: Energie sparen ohne Doppelverglasung*	*06 November 2012*	*Build up - Portal*	*Industry*		*Germany*
10	*Press releases*	*EnBauSa*	*Energiesparfenster sollen künftig weniger wiegen*	*22 November 2012*	*EnBauSa*	*Civil Society, Industry*		*Germany*
11	*Web*	*Bavarian Research Alliance*	*Introduction to the HarWin project for European Universities, small-and medium sized enterprises and public administrations*	*2013*	*Official homepage*	*Medias*		*Germany*
12	*Exhibitions*	*Messe München GmbH*	*BAU 2013*	*14-19 January 2013*	*Munich, Germany*	*Scientific Community, Industry, Civil Society, Policy Makers, Medias*	*more than 250,000 visitors from 156 countries*	*Worldwide*
13	*Conference*	*Institute of Werkstoffverarbeitung, University of Bayreuth & Bayern Innovativ GmbH*	*Glass materials for energy-efficient building*	*16 January 2013*	*Nuremberg, Germany*	*Scientific Community*	*Around 80 experts*	*Germany*
14	*Exhibitions*	*NürnbergMesse GmbH*	*Fensterbau/Frontale1*	*07-09 March 2013*	*Mumbai, India*	*Industry*	*108,000 visitors*	*Worldwide*
15	*Conference*	*JEC Group*	*JEC*	*12-14 March 2013*	*Paris,France*	*Scientific Community, Industry*	*250,000 visitors from 100 countries*	*Worldwide*

16	Conference	Phantoms Foundation, CIC nanoGUNE, Donostia Internacional Physics Center & Euskampus	IMAGINENANO	23-26 April 2013	Bilbao, Spain	Scientific Community, Industry Policymakers and Investors	Around 95 participants	Spain
17	Progress Meetings		HarWin Progress Meeting	24-25 April 2013	Munich, Germany	HarWin Consortium		Germany, Italy, Poland, Belgium, UK, Switzerland, Finland
18	Conference	German Society of Glass Technology (DGG)	87th DGG Meeting	27-29 May 2013	Bremen, Germany	Scientific Community		Germany
19	Conference	Enterprise Europe Network & Spinverse Ltd	EuroNanoForum 2013	18-20 June 2013	Dublin, Ireland	Scientific Community, Industry	Nearly 1,500 active members from 50 countries	Worldwide
20	Others	JRC	Contribution to EU policies/regulations: Ecodesign Preparatory Study on Windows (DG Energy)	July 2013 - May 2015	http://www.ecodesign-windows.eu/	Policy Makers		European Union
21	Conference	The Department for Polymer Engineering, University of Bayreuth & New Materials Bayreuth GmbH	29th International Conference of the Polymer Processing Society (PSP-29)	15-19 July 2013	Nuremberg. Germany	Scientific Community, Industry	Over 730 participants from 52 countries	Germany
22	Conference	Korean Scientists and Engineers Association in the UK (KSEAUK)	EU-Korea conference on Science and Technology 2013	24-26 July 2013	Brighton, United Kingdom	Scientific Community	over 1,400 members from nine European countries as well as Korea	United Kingdom

23	*Conference*	*Institute of Technology and Testing of Building Materials, Graz University of Technology*	*Sustainable building Conference 2013*	*25-28 September 2013*	*Graz, Austria*	*Scientific Community*	*Nearly 500 participants from 20 countries*	*Austria*
24	*Conference*	*ift Rosenheim*	*Rosenheimer Fenstertage 2013*	*10-11 October 2013*	*Rosenheim, Germany*	*Scientific Community*	*979 experts from 23 countries*	*Germany*
25	*Progress Meetings*		*HarWin Progress Meeting and Exploitation Seminar*	*10-11 October 2013*	*Brussels, Belgium*	*HarWin Consortium*		*Germany, Italy, Poland, Belgium, UK, Switzerland, Finland*
26	*Trade Fair*	*Messe Duesseldorf GmbH*	*K – International Trade Fair No.1 for Plastics and Rubber*	*16-23 October 2013*	*Düsseldorf, Gemany*	*Scientific Community, Industry, Civil Society*	*Over 220,000 visitors from 59 countries*	*Germany*
27	*Conference, Exhibitions*	*kulturidee GmbH*	*Lange Nacht der Wissenschaften*	*19 October 2013*	*Fürth-Erlangen-Nürnberg, Germany*	*Scientific Community, Civil Society, Policy Makers, Media*	*30,000 visitors*	*Germany*
28	*Project Review*	*The European Construction Technology Platform (ECTP) & European Commission of Industrial technologies (EeB)*	*EeB PPP Project Review*	*November 2013*	*Website*	*Medias*		*European*
29	*Conference*	*Bayern Innovativ GmbH*	*Bau Innovativ 2013*	*14 November 2013*	*Fürstenfeldbruck, Germany*	*Scientific Community,*	*around 250 participants*	*Germany*

						Industry, Civil Society, Policy makers		
30	*Others*	*JRC*	*Contribution to EU policies/regulations: CEN TC350 (PEFCRs) for construction products*	*20 November 2013*		*Policy Makers*		*European Union*
31	*Thesis*	*Kinga Wisniewska (supervisor: M. El Fray, W. Ignaczak)*	*Student thesis: "Influence of modification of PP/PBT blends"*	*11 February 2014*	*WUT*	*Scientific Community*		*Poland*
32	*Articles published in the popular press*	*Pegnitz Newspaper*		*March 2014*		*Civil Society*	*around 12000 readers around Nuremberg*	*Germany*
33	*Exhibitions*	*NürnbergMesse GmbH*	*Fensterbau/Frontale 2014*	*26-29 March 2014*	*Nuremberg, Germany*	*Industry*	*108,000 visitors*	*Worldwide*
34	*Workshop*		*HarWin Progress Meeting & 1st workshop*	*27-28 March 2014*	*Szczecin, Poland*	*HarWin Consortium*		*Germany, Italy, Poland, Belgium, UK, Switzerland, Finland*
35	*Newspaper*	*Hersbrucker Zeitung*	*Franken-Wissen für Europa*	*28 March 2014*	*Local German newspaper*	*Civil Society, Industry*	*ca. 80,000 readers*	*Germany*
36	*Workshop*	*European Commission*	*Impact of the Energy-Efficient Buildings Public-Private Partnership*	*1-2 April 2014*	*Brussels, Belgium*	*Industry*	*123 Participants*	*European Union*
37	*Exhibitions*	*Deutsche Messe*	*Hannover Messe 2014*	*07-11 April 2014*	*Hannover, Germany*	*Scientific Community, Industry, Civil Society, Policy Makers, Medias*	*736,000 visitors from 53 countries*	*Worldwide*

38	Conference	The Institute of Chemical Engineering Sciences (FORTH /ICE-HT) & Spinverse Ltd	Industrial Technologies 2014	09-11 April 2014	Athens, Greece	Scientific Community, Industry, Policy makers	1,200 visitors from over 50 countries	Greece
39	Press releases	Bavarian Research Alliance	BayFOR Annual Report 2013	July 2014	Permalink	Scientific Community, Industry, Policy Makers, Medias		European Union
40	Report Summary	CORDIS - European Commission's primary public repository	Periodic Report Summary 1 - HarWin	24 July 2014	Website	Scientific Community, Industry		European
41	Workshop	JRC	HarWin Progress Meeting & 2nd Workshop "Life Cycle Environmental Assessment (LCEA)"	11 September 2014	Ispra, Italy	Harwin consortium		Germany, Italy, Poland, Belgium, UK, Switzerland, Finland
42	Exhibitions	Messe Düsseldorf GmbH	Glasstec	21-24 October 2014	Düsseldorf, Germany	Scientific Community, Industry, Civil Society, Policy Makers, Medias	over 42,000 visitors from 87 countries	Worldwide
43	Exhibitions	Reed Expositions France	Equipbaie	11-14 November 2014	Paris, France	Industry	20,000 visitors	France

44	Conference	The Society of Environmental Toxicology and Chemistry (SETAC) & the Faculty of Technical Sciences Novi Sad	SETAC 20th LCA Case Study Symposium	24-26 November 2014	Novi Sad, Serbia	Scientific Community, Industry	Over 115 participants	Serbia
45	Exhibitions	Messe München GmbH	BAU 2015	19-24 January 2015	Munich, Germany	Scientific Community, Industry, Civil Society, Policy Makers, Medias	more than 250,000 visitors from 156 countries	Worldwide
46	Conference	OO Energiesparver band Austria	European Smart Windows Conference	25 February 2015	Wels, Austria	Scientific Community, Industry	750 participants from 64 countries	European Union
47	Conference	JEC Group	JEC Europe 2015	10-1 March 2015	Paris, France	Scientific Community, Industry	250,000 visitors from 100 countries	Worldwide
48	Press Release	Bavarian Research Alliance	BayFOR News	June 2015	Permalink	Scientific Community, Industry, Policy Makers, Medias		European Union

49	Exhibitions	Enterprise Europe Network & Spinverse Ltd	EuroNanoForum 2015	10-12 June 2015	Riga, Latvia	Scientific Community, Industry, Civil Society, Policy Makers, Medias	1,200 delegates, among which 150 high level speakers	European Union
50	Press release	Bavarian Research Alliance	BayFOR Annual Report 2014	July 2015	Permalink	Scientific Community, Industry, Policy Makers, Medias		European Union
51	Exhibitions	Laboratory for Thin Films Nanosystems and Nanotech, Aristotle University Technology, NanoNet	NANOTEXNOLOGY 2016	04-08 July 2015	Thessaloniki, Greece	Scientific Community, Industry, Civil Society, Policy Makers, Medias	2,000 researchers, scientists, engineers, bsiness and technical professionals	European Union
52	Workshop		HarWin Exploitation Workshop	14 August 2015	Nuremberg, Germany	HarWin Consortium	17 Participants	Germany, Italy, Poland, Belgium, UK, Switzerland, Finland
53	Thesis	Msc. Kanat Krgyzbaev	PhD Thesis: process development for glass flakes with controlled morphology	3 years (estimated)	UBT CMP	Scientific Community		Germany
54	Thesis	M Eng bhwana Agrawal	"Ionomer-Glass-Flake composite membranes"	3 years	UBT CMP	Scientific Community		Germany
55	Thesis	Student Team Project	Student thesis : "Glass Flake PVB polymer membranes from solution process"	1 year	UBT CMP	Scientific Community		Germany
56	Thesis	Student Thesis	"Ionomer-GF-composites from solution	1 year	UBT CMP	Scientific		Germany

			based process"			*Community*		
57	*Thesis*	*Student Thesis*	*"Master Thesis (planned for 2013): Simulation and experimental verification of thermal properties of glass flake-PVB composite membranes"*	*1*	*UBT CMP*	*Scientific Community*		*Germany*
58	*Thesis*	*F Somorowsky*	*Dissertation: In the context of his PHD-thesis he analyses porous Vycor-glass as a material for the regulation of the room-climate*	*3 years*	*Fraunhofer ISC*	*Scientific Community*		*Germany*
59	*Thesis*	*Dipl.-Ing. Wojciech Ignaczak*	*PhD thesis: "Fiber-reinforced composites based on polymer blend matrix*	*3 years*	*WUT*	*Scientific Community*		*Germany*
60	*Others*	*JRC, IES*	*Integration of environmental information of the HarWin window into existing databases for energy simulation of buildings <VE software>*			*Scientific Community, Industry*		*Worldwide*
61	*Publications*	*JRC*	*Publication of a dataset on a manufacturing process relevant for the HarWin window production*			*Scientific Community, Industry*		*European Union*
62	*Others*	*JRC*	*Contribution to EU policies/regulations: Resource efficiency potentials for the building sector (DG GROW / ENV)*	*2013-2015*		*Policy Makers*		*European Union*
63	*Others*	*JRC*	*Cluster activity between the sister projects on Smart Windows*			*Scientific Community, Industry*		*European Union*
64	*Conference*	*ISC*	*Annual conference of the German Society of Glass Technology (this year in cooperation with the American Ceramic Society) about new investigations of glass in the industry and research* www.**dgg-gomd**.org	17 - 21/05/2015	Miami/Florida	*Scientific Community, Industry*		*Worldwide*
65	*Web*	*ISC*	*Annual Report of Fraunhofer ISC* *send to many project partners and visitors of the Fraunhofer ISC, published in the internet*	*Autumn 2014*		*Scientific Community, Industry*		*European Union*

66	*Workshop*	*ISC*	**Ferdinand Somorowsky "Glass-PCM-Polymer-Composites for Glazing Panes"** HarWin workshop Material solution for energy efficient buildings – fenestration and façade	*28/03/2014*	*Szczecin*	*Scientific Community, Industry*		*Poland*
67	*Master Thesis*	*Anna Olek*	*Student thesis: "Preparation of polymer-glass composites"*	*9 September 2014*	*WUT*	*Scientific Community*		*Poland*
68	*Master Thesis*	*Kinga Wisniewska (supervisor: M. El Fray)*	*Student thesis: "Thermal and rheological properties of composites containing basalt fibres"*	*30 September 2015*	*WUT*	*Scientific Community*		*Poland*
69	*Conference talk*	*M.Schroecker (GX)*	*European Smart Windows Conference* *Talk: Phase change material as a storage element in window systems*	*25 February 2015*	*Wels, Austria*	*Scientific Community, Industry*	*750 participants from 64 countries*	*European Union*
70	*Conference talk*	*M.Schroecker (GX)*	Czech Council of Building Envelope Specialists Conference FP7 Smart Window projects presented in the talk "The future of windows - Materials innovation for energy efficient building envelopes"	17/03/2015	Prague / Czech Republic	*Scientific Community, Industry*	300 participants	*Czech Republic*

4.2.2 Part B1

4.2.2.1 List of application for patents, trademarks, etc.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[6]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Material and applications	yes	06-2016	Not yet available	Polymer-glass flake composites for building applications	B. Scharfe, Ch. Wehmann, M. Willert-Porada, University of Bayreuth
Material and application	yes	06-2016	Not yet available	Luminescent Down Conversion material for solar energy harvesting	K. Kyrgyzbaev, A.Saberi, B. Scharfe, M. Willert-Porada, University of Bayreuth
Material and application	yes	06-2016	Not yet available	Multifunctional polymer-glass composites for energy applications	B. Agrawal, K. Kyrgyzbaev M. Willert-Porada, University of Bayreuth

[6] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2
Please complete the table hereafter:

4.2.2.2 List of exploitable foreground

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Fore seen emb argo date	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Cheap and stiff interlayer (glass filler)	YES		Lamination interlayer with superior characteristic and/or price	• Construction • Manufacture of glass and glass products	Expected 2016 – 2017	In preparation	UBT, InG, EF
Commercial exploitation of R&D results	Novel frame concept	YES		Window frame with superior characteristic	• Construction	Expected after 2017	None planned	UBT, NMB, ISMTX, WUT
Commercial exploitation of R&D results	Luminescent down conversion (LDC) glazing applications	YES		Windows with increased visible light transmission	• Construction • Manufacture of glass and glass products	Expected 2016 – 2017	In preparation	UBT
Commercial exploitation of R&D results	Glass containing phase change materials (PCM)	YES		Windows with energy harvesting functionality	• Construction • Manufacture of glass and glass products	Expected 2016 – 2017	None planned	Fraunhofer ISC, GX
Commercial exploitation of R&D results, General advancement of knowledge	Simulation environments including HarWin glassflake laminates and PCM glazing	Code YES, use of environments NO		Improved simulation ability for advanced glazing materials	• Construction	Available	None planned	IES, JRC, GX
Exploitation of R&D results via standards, exploitation of results through	Life Cycle Environmental Analysis (LCEA) dataset and tool	NO			• Construction	Available	None planned	**JRC, IES**

[1] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[8] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Fore seen emb argo date	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
EU policies								

4.2.2.3 Detailed explanation of exploitable foreground

1) Cheap and stiff interlayer (glass filler)	
Purpose	Through the addition of glass flakes to existing interlayer polymers, it was possible to increase the stiffness of these materials. This allows the manufacturing of structurally stable glazing elements using much thinner glass panes, thereby enabling lighter windows.
Exploitation of foreground (by whom, when)	Partners UBT and InG are in the best position to exploit the foreground, for example through a cooperation or a licensing agreement with a manufacturer of interlayer polymers (such as i.e. Kuraray). First discussions with company representatives have been started as part of the exploitation activities in project HarWin.
IPR exploitable measures taken or intended	IPR measures are currently in discussion at UBT in cooperation with their patent office. These might lead to the filing of patent applications in the end of 2015 or the beginning of 2016.
Further research necessary	Right now the haze of the HarWin laminates is higher than that of standard windows (at about 2.5%). This is no problem for applications such as daylighting elements or sky lights, but might inhibit use in standard glazing. By optimizing the particle shifting and cleaning and matching refracting indices of the glass particles even closer to the used polymer this can be improved further, thereby increasing the possible applications for the project results.

Potential/expected impact	Lighter windows reduce the material needs both in the glazing itself, but also in the framing and mounting solutions. This has the potential to reduce the grey energy of the building and the transportation energy needs in line with the weight reduction potential (25 – 50%). Additionally stiffer glazing elements might allow the enlargement of structurally sound applications for glass in general, potentially replacing energy intensive materials such as concrete, steel or aluminium.

2) Novel frame concept	
Purpose	The novel frame concept developed in project HarWin replaces standard frame materials with a sandwich construction encasing a foam core with stiff composite tapes including basalt fibers. These materials have the potential to provide stiffness and thermal insulation required in window frames using much thinner profiles.
Exploitation of foreground (by whom, when)	The material concept can best be exploited by UBT and NMB in combination with the partners ISMTX and WUT. Cooperations with window frame manufacturers would be beneficial and have already been initiated during the project exploitation activities.
IPR exploitable measures taken or intended	For the moment, no IPR activities are planned for this result.
Further research necessary	Although the material concept has been developed and demonstrated, further development is necessary to enable a use in standard window frame applications. Especially the structural stability of the frame for larger windows and the addition of mechanisms for opening and closing and sealing of movable windows has to be elaborated. Another area of research is the optimisation of the combination of frame and glazing, which is currently done using fixation through glue.

Potential/expected impact	Improvements in thermal insulation of window frames has the potential to substantially cut building energy consumption, since the window frame is currently the weakest part in a building's façade (compared to glazing and opaque façade). Thinner framing structures would furthermore allow for more light to enter into a building, thereby increasing the visual comfort of the building users.

3) Luminescent down conversion (LDC) glazing applications	
Purpose	By turning invisible and harmful UV radiation into wavelength visible to the human eye, luminescent down conversion has the potential to increase visual comfort for building users. In terms of energy use the application of such glazings can reduce the electricity consumption for lighting and at the same time cut down the cooling energy demand, since the secondary heat from lamps is also reduced.
Exploitation of foreground (by whom, when)	The partner UBT is in the best position to exploit the result, since know-how and research results are concentrated with the institution. To bring the product to the market industrial glass partners might be helpful. Based on the results and dissemination from project HarWin, discussions on cooperations will be started during 2016.
IPR exploitable measures taken or intended	The possibility for patent applications is currently investigated by UBT and NMB together with the UBT patent office. Possible applications will be filed during 2016.
Further research necessary	Optimization of the glass process for use in standard window glazing has to be conducted, most likely in cooperation with a commercial glass partner.
Potential/expected impact	Increases in human well-being and reductions in building energy consumptions are achievable through this solution, with the latter expected to be in the area of several %pts in the right buildings and climates.
4) Glass containing phase change materials (PCM)	

Purpose	To enable energy harvesting, high density thermal storage in the form of phase change material (PCM) was incorporated in glazing. Through the use of glass particles for encapsulation and polymers between glass panes as carrier matrix for the glass particles, a novel way of creating stable PCM inclusion in glazing elements was developed. Due to the material properties and refractive indices of the materials used such solutions are not fully transparent, but manifold applications can be found in daylighting elements and translucent walls. By increasing daylighting inside building spaces and regulating energy transmission, it was shown in simulations that building cooling energy demands can be lowered significantly.
Exploitation of foreground (by whom, when)	The foreground can best be exploited by the company GX, which already has similar products in the market, together with the research partner Fraunhofer ISC and potentially other industrial partners from outside the consortium. Internal discussions have been started and will be continued after the end of the project.
IPR exploitable measures taken or intended	For the moment, no IPR activities are planned for this result.
Further research necessary	In order to achieve effects in the range quantified during the simulation studies, the content of PCM within the glazing should be increased. This can be done via better infiltration methods or by enabling a higher loading factor of the PCM containers within the polymer. For this the performance and long-term compatibility with a wider range of polymers needs to be determined, to allow for a better tailoring of the carrier matrix to the application demands. Up scaling of the encapsulation process needs to be developed further to turn the solution into a commercially viable product.
Potential/expected impact	As shown in an extensive set of building simulations for different building types and European climates, the application of a thin layer of the PCM material was able to achieve reductions in the range of 10 – 20% in the right climates (significant cooling demand during the day, average night temperatures below 20°C for night cooling also during summer months). Especially on the background of increasing global temperatures, ever higher glass shares in office buildings and increasing user demands for stable indoor temperatures it is clearly visible that the solution has the potential to enable large scale energy reductions when applied to buildings.

5) Simulation environments including HarWin glassflake laminates and PCM glazing	
Purpose	Through the work performed in project HarWin, complex glazing properties (HarWin interlayers, PCM containing glazing) where added to building simulation software and used for extensive simulation studies. These activities helped to increased the understanding of building level impacts of the research results and also influenced the research work within the project. Furthermore the simulation environments are now available for further studies, thereby supporting the commercialization of project results by providing optimisation and decision tools to the partners and potential clients.
Exploitation of foreground (by whom, when)	The new modules for HarWin specialised panes (including glass flake laminates) are included in the simulations software Virtual Environment from the partner IES and will henceforth be disseminated with this software tool. The PCM glazing modules are implemented in the software environment used by the partner GX and will be exploited by them. Through the use for further optimisation and also as decision tools for clients, the entire consortium will profit from the tools and participate in their exploitation.
IPR exploitable measures taken or intended	Since the discussed results are software tools, no IPR activities are planned.
Further research necessary	At the moment, all the research goals have been met and the additions of capabilities to the software environments have been completed. Based on the further developments of HarWin solutions after the end of the project, there might be scope for further work on the software tools to capture any improvements.
Potential/expected impact	The impact of these tools was already felt within the project by allowing for a quantification and an optimisation for the research results from the other work packages. After the end of the project the tools will help with the exploitation and commercialization of the other results, as well as allowing for the establishment of general knowledge on the impact of these solutions on a building level.

6) Life Cycle Environmental Analysis (LCEA) dataset and tool	
Purpose	Led by partner JRC, extensive Life Cycle Analysis activities where conducted throughout the entire project. These led to the establishment of datasets and analysis tools allowing for a very detailed quantification of the environmental impact of the solutions developed in the project. By providing all the consortium partners with access to a detailed yet easily usable analysis tool, these quantifications were also used within the project to optimise results for minimal environmental impact. Beyond the end of the project, the datasets and tools will be available to further the knowledge and help with developments in the area of specialized glazing solutions.
Exploitation of foreground (by whom, when)	The key knowledge lies with the partner JRC, however through the publishing of datasets and tools the entire consortium and wider public can profit from the project results.
IPR exploitable measures taken or intended	Since the datasets and tools are to the largest part publicly available, no IPR measures are planned.
Further research necessary	The research aims have been met, however future work in the field will most likely lead to a constant updating and enhancement of the results.
Potential/expected impact	By providing a much better view on environmental impacts of novel glazing solutions, the LCEA work was able to influence the project work within HarWin to achieve lower overall environmental impacts. By increasing knowledge and ease of analysis, the datasets and tools are expected to help reduce environmental impacts over a large range of products and processes in the glazing and construction industries.