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TNO report

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Potential Impact of High Performance Glazing on Energy and CO_2 Savings in Europe

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Contents

Executive Summary

The major European manufacturers of architectural glass, joined in GLASS FOR EUROPE, requested an independent study on the potential energy and CO_2 savings in the 28 EU Member States resulting from the application of high performance glazing.

This report quantifies the potential impact of the application of high performance glazing on annual energy savings and CO_2 reductions for EU28 for five scenarios. This report updates two earlier reports [1,2].

The calculation method used is a monthly method, i.e. a method where the energy balance of the building is set up per month, each with a different ambient temperature and solar irradiation. This method corresponds to the EPBD standard developed for the determination of heating and cooling loads of buildings. Information on building stock, material properties and meteorological data comes from international studies and statistics.

Sets of two calculations are used to determine the potential energy savings:

- in the first calculation, the annual heating and cooling energy is calculated for the building with reference glazing, which is currently present in existing buildings or is expected to be applied in future buildings;
- in the second calculation, the annual heating and cooling energy is calculated for the same building with high performance glazing.

The thermal properties for the reference glazing and for the high performance glazing are provided by Glass for Europe for the different buildings, regions, building periods and temporal horizons [Annex 1].

Subtraction of the annual energy demands for heating and cooling resulting from the two calculations yields the potential annual energy savings. Subsequently, potential CO_2 reductions are derived from the annual energy savings and the assumed country and period specific carbon intensities of their energy mix.

The annual energy savings and CO_2 reductions are calculated for five scenarios of penetration of high-performance glazing:

Scenario 1: application of high performance glazing in 1% of the buildings in 2020;

Scenario 2: application of high performance glazing in 1% of the buildings in 2030;

Scenario 3: application of high performance glazing in 10% of the buildings between 2020 and 2030 simulating the impact of a 1% per year window renovation rate over 10 years;

Scenario 4: application of high performance glazing in all buildings in 2030;

Scenario 5: application of high performance glazing in all buildings in 2050;

The differences in savings between scenario 1 and 2 and between scenario 4 and 5 are due to developments in building stock, system efficiencies, integration rates of cooling systems and carbon intensities between 2020, 2030 and 2050.

In scenarios 1 and 2 high performance glazing is applied on renovation buildings such that the floor area renovated is 1% of the total floor area of all buildings in respectively 2020 and 2030. In scenarios 3 high performance glazing is applied on

renovation buildings with a total floor area of 1% of the total floor area of all buildings in the period from 2020 to 2030 (1% annually). While scenarios 1, 2 and 3, focus on renovation of existing buildings only, scenarios 4 and 5 comprise the savings induced by high-performance glazing being installed on both renovated buildings and new buildings.
For all scenarios, expected boundary conditions such as system efficiencies, air conditioning integration rates, demolition rates and carbon intensities are taken into account for the specified periods in time.

The table below presents the results for the five scenario's summed for the EU28 Member States.

Scenario	Building stock fraction	Horizon	Annual energy savings total		Annual energy savings for heating		Annual energy savings for cooling		Annual CO_2 reduction	
	[%]	[year]	[kToe]	[%]	[kToe]	[%]	[kToe]	[%]	[kTon]	[%]
1	1%	2020	902	0,37	858	0.39	44	0,14	1171	0,33
2	1%	2030	1272	0,49	1203	0.53	69	0,20	1572	0,46
3	10%	2030	9065	3,5	8578	3.8	487	1,5	11473	3,3
4	100%	2030	75514	29	70028	31	5486	16	94230	28
5	100%	2050	67210	37	60554	39	6656	28	68512	37

The presented savings and CO_2 reductions for scenarios 1, 2 and 3 are proportional to the building stock fraction implemented with high performance glazing.

This report provides a quantification of the potential energy savings and CO_2 reductions across Europe as result of the use of high-performance glazing in buildings. It quantifies both the impact of an increase in glazing performance and of an increase in retrofitting rates.

It should be noted that this study focuses on the impact of improved windows only. Renovation of buildings often includes a combination of renovation measure which, while further increasing the total savings, dilutes shares of savings attributable to a single component; e.g. windows.

1 Introduction

1.1 Issue of impact of high performance glazing on energy and CO_2 savings

GLASS FOR EUROPE represents the major European manufacturers of architectural glass, AGC Glass Europe, Guardian Glass, NSG group, Saint Gobain Glass and Sisecam Flat Glass, as well as national associations of flat glass processors and transformers in major European producing countries.

GLASS FOR EUROPE believes that insufficient attention has been paid by policymakers and legislators to the significant contribution of glazing to reducing heating and air conditioning needs from buildings and thus to reducing energy consumption and CO_2 emissions from the building sector.

Therefore, GLASS FOR EUROPE initiated an independent study for the calculation of the energy and CO_2 savings in each of the 28 EU Member States as a result of the use of high performance glazing, i.e. double- or triple-insulating glass units made of both or either Low-E or Solar-Control coated glass optimized for the different building types and regions.

Results of this study, carried out by TNO, are presented in this report. The study covers dwellings and non-residential buildings, new buildings as well as existing buildings having their windows replaced.

Calculations have been made for developments over the coming years until 2030 and 2050 for the 28 EU Member States. This study does not include potential extra savings which could be generated by dynamic glazing or glazing integrated photovoltaics technologies. Although these technologies could become more wide-spread in a 2050 horizon, they were left out of the scope of this study due to the additional methodological and simulation complexities that their integration would have generated.

The outcome of this work is relevant to inform policy-makers in the context of debates on energy-efficiency, buildings’ energy performance and decarbonisation policies.

1.2 Approach

Determination of the energy and CO_2 savings has been based on the European methods for assessment of the energy performance as elaborated for the Energy Performance of Buildings Directive. Heating and cooling loads of buildings as calculated according to this EN ISO 13790 method [3] have been incorporated in a calculation tool.

Sheets containing input data for the calculations as well as output sheets for final processing are provided to Glass for Europe. There are input data on country information, description of buildings including operation of installations, building stock, glazing properties and meteorological data. Final processing involves conversion of heating and cooling loads for the various situations into energy savings (thermal and electrical) and further CO_2 savings for clusters of countries and for individual Member States. Input and output details of the tool are described in Chapter 2.

Five scenarios of penetration of high performance glazing have been studied using the calculation tool for quantification. The scenarios and the corresponding energy savings are presented in Chapter 3.

TNO's work has been followed by a small GLASS FOR EUROPE Working Group. Members of this group contributed to the study with specific data on glazing properties for the European countries as well as references to available European data and studies.

2 Calculation method and tool

2.1 Monthly method from ISO 13790 for window energy calculations

2.1.1 Reference to the calculation method

Within the set of standards supporting the Energy Performance of Buildings Directive ([3]) describes the calculation of heating and cooling loads of buildings.

The monthly method for determination of heating and cooling loads of buildings has been incorporated in the calculation tool created for the study in this report.

2.1.2 Building energy balance

In EN ISO 13790, the monthly energy need for space heating is calculated according to:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \cdot Q_{H,gn} \quad (1)$$

where for each month:

$Q_{H,ht}$ is the total heat transfer by transmission and ventilation of the building;

$Q_{H,gn}$ are the total solar and internal heat gains of the building;

$\eta_{H,gn}$ is the dimensionless gain utilization factor.

The monthly energy need for space cooling is calculated according to:

$$Q_{C,nd} = Q_{C,gn} - \eta_{C,ls} \cdot Q_{C,ht} \quad (2)$$

where for each month:

$Q_{C,ht}$ is the total heat transfer by transmission and ventilation of the building;

$Q_{C,gn}$ are the total solar and internal heat gains of the building;

$\eta_{C,ls}$ is the dimensionless utilization factor for heat losses.

2.1.3 Heat balance elements

Leaving out the indices H for heating and C for cooling, the total heat transfer of the building is given by:

$$Q_{ht} = Q_{tr} + Q_{ve} \quad (3)$$

where for each month:

Q_{tr} is the total heat transfer by transmission of the building;

Q_{ve} is the total heat transfer by ventilation and infiltration of the building.

The total heat gains of the building are given by:

$$Q_{gn} = Q_{int} + Q_{sol} \quad (4)$$

where for each month:

Q_{int} is the sum of the internal heat gains of the building;

$Q_{sol\ e}$ is the sum of the solar gains of the building.

Gain utilization factor $\eta_{H,gn}$ and heat loss utilization factor $\eta_{C,ls}$ are functions of the heat balance ratio γ, being Q_{gn}/Q_{ht}, and a numerical parameter that depends on the building thermal inertia. Figures1 and 2 illustrate the gain and heat loss utilization factor for the heating and cooling load calculation of the building respectively.

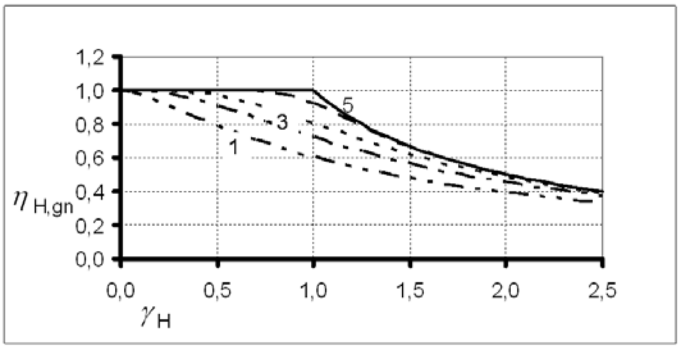

Figure 21 Illustration of gain utilization factor for heating mode, for 8 hours (low inertia, key 1), 1 day, 2 days, 1 week and infinite (high inertia, key 5) time constants.

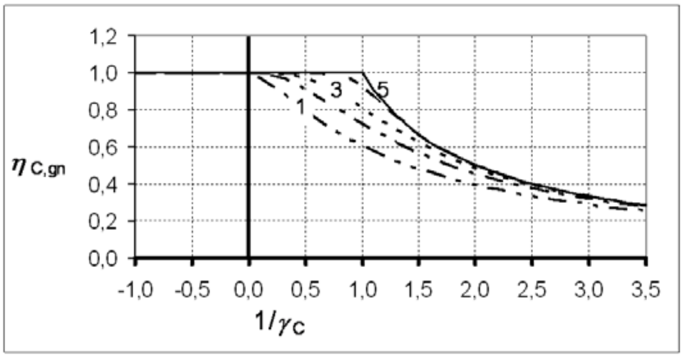

Figure 2 Illustration of loss utilization factor for cooling mode, for 8 hours (low inertia, key 1), 1 day, 2 days, 1 week and infinite (high inertia, key 5) time constants.

2.1.4 *Calculation at window level*

Use of the monthly calculation method for the window energy balance gives the following energy performance per m² window area A_w for heating:

$$Q_{H,nd,w} = Q_{H,ht,w} - \eta_{H,gn} \cdot Q_{H,gn,w} \quad (5)$$

For cooling it is:

$$Q_{C,nd,w} = Q_{C,gn,w} - \eta_{C,ls} \cdot Q_{C,ht,w} \quad (6)$$

Leaving out the indices H and C, the window energy terms are as follows:

$$Q_{ht,w} = U_w \cdot (\theta_i - \theta_e) \quad (7)$$

and

$$Q_{gn,w} = g_w \cdot I_{sol} \quad (8)$$

where:

U_w is the U-value of the window, in W/(m²K);

g_w is the dimensionless total solar energy transmittance of the window;

$\theta_i - \theta_e$ is the difference between internal and external temperatures on a monthly basis, in K;

I_{sol} is the solar irradiance, the total monthly energy of the solar irradiation per m² window with given orientation and tilt, in MJ/m².

Following ISO 15099, the window U- and g-values can be derived using:

$$U_w = \frac{U_g * A_g + U_f * A_f + \psi * l_\psi}{A_w} \quad (9)$$

where:

U_w is the U-value of the window, in W/(m²K);
U_g is the U-value of the glazing, in W/(m²K);
U_f is the U-value of the frame, in W/(m²K);
A_w is the area of the window, in m²;
A_g is the area of the glazing, in m²;
A_f is the area of the frame, in m²;
l_ψ is the perimeter length, in m;
ψ is the linear thermal transmittance, in W/(m·K).

The calculation process involves:

1. From selected climate and window orientation: assigning of matching ($\theta_i - \theta_e$) and I_{sol} per month.
2. From the window properties: assigning U_w, g_w and A_w.
3. From selected building and occupancy: assigning of matching $\eta_{H,gn}$ and $\eta_{C,ls}$ per month.

2.1.5 *Validation of the calculation tool*

The monthly calculation method has been validated against four reference cases as described in EN-ISO 52017-1:2017. These reference cases present an office room with a west oriented window and different combinations of building inertia, internal heat gain and g-value. Reference values for heating and cooling load of the room come from calculations using different dynamic mathematical models. Table 1 presents calculation results of the tool in comparison to the reference values.

Table 1 Comparison of heating and cooling loads for an office room from the calculation tool with reference calculations according to CEN EN 15265.

Case	Construction	Internal gain W/m²	g-value		Tool kWh	Reference kWh	Difference
1	Light	20	0.20	$Q_{H,nd}$	832	748	11%
				$Q_{C,nd}$	249	234	7%
2	Heavy	20	0.20	$Q_{H,nd}$	791	723	10%
				$Q_{C,nd}$	189	201	-6%
3	Light	0	0.20	$Q_{H,nd}$	1430	1369	5%
				$Q_{C,nd}$	40	43	-6%
4	Light	20	0.72	$Q_{H,nd}$	617	567	9%
				$Q_{C,nd}$	1648	1531	8%

The comparison shows that the calculation tool is in line with the reference calculations. Maximum difference is about 10%.

2.2 Structure and contents of the calculation tool

Figure 3 describes the structure of the MS Excel based calculation tool, called EUCO2, Version 2.00. The tool core contains the calculation routine as described in Section 2.1. These calculations are performed for multiple combinations of country clusters coupled to climate, building type, building age and type of glazing. Hence, a matrix is defined for all combinations to be calculated. Afterwards, calculation results are postprocessed to reveal totals of energy use and CO_2 production as well as the energy savings and CO_2 reductions.

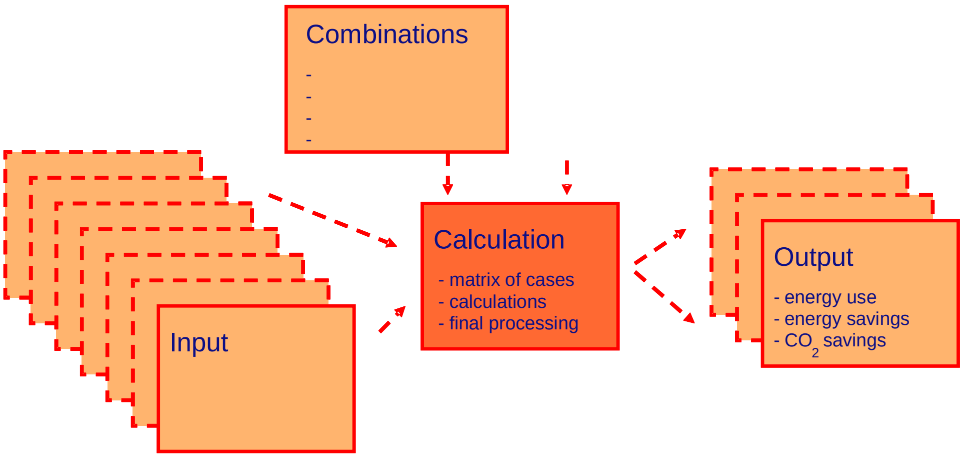

Figure 3 Structure of the tool for calculation of the heating and cooling load of buildings.

2.2.1 *Definition of country clusters coupled to climate*

Calculations are performed for seven different clusters of countries, each of the clusters having its own set of meteorological data. Table 2 presents the distribution of the EU Members States over the country clusters.

Table 2 Distribution of the 28 EU Member States over the country clusters.

North	
	Finland
	Sweden
Central maritime	
	Belgium
	Denmark
	Ireland
	Luxemburg
	The Netherlands
	United Kingdom
	France
Central continental	
	Austria
	Germany
South	
	Cyprus
	Greece
	Italy
	Malta
	Portugal
	Spain

Baltics	
	Lithuania
	Latvia
	Estonia
Central	
	Poland
	Czech republic
	Hungary
	Slovakia
	Slovenia
	Croatia
Romania, Bulgaria	
	Romania
	Bulgaria

Table 3 defines the link between country clusters and reference meteorological data. The data have been derived from Meteonorm ([6]).

Table 3 Link between country clusters and reference meteorological data.

Country cluster	Location of reference meteorological data
North	Stockholm
Central maritime	London
Central continental	Munich
South	Rome
Baltics	Riga
Central	Prague
Romania, Bulgaria	Bucharest

2.3 Definition of building types and building stock

Calculations are performed for five different building types, both residential and non-residential buildings, like offices and schools. Table 4 defines the building types by way of floor, wall, window and roof area.

Building stock has been composed from residential and non-residential buildings from the following periods, i.e. before 1975 and periods 1975 -1990, 1991 - 2002, 2002 - 2006 and 2007 - 2020, 2021 - 2030, 2031 - 2050. For the period before 1975, distinction has been made between refurbished and non-refurbished buildings.

In the previous studies [1], [2], information on the building stock were based on the Ecofys studies for Eurima and EuroACE ([8], [9] and [10]). The existing tool database was compared to various recent building stock databases as the Online European Database ([7]) and the Odyssee and Mure databases ([11]). It was not feasible to incorporate data from recent databases directly but new databases were used to update the existing database for the growth of floor area per country cluster.

For the majority of the calculations, it is assumed that the net growth in floor area is between 0.8 and 3.4% per year depending on country clusters equally distributed over building types taken from the European Database [7]. The annual demolition rate is assumed to be 0.2% per year [7,11].
Table 5, 6 and 7 define the distribution of floor area over the building types, building periods and country clusters in respectively the year 2020, 2030 and 2050.

Table 4 Definition of building types.

Building type	**Dwelling**	**Apartment building small**	**Apartment building large**	**Non-residential small**	**Non-residential large**
Function: - 1 = residential - 2 = office, school, etc.	1	1	1	2	2
Length of the building [m]	10	70	210	70	210
Width of the building [m]	5	10	15	15	25
Height of the floor [m]	2.7	3.0	3.0	3.0	3.0
Number of floors	2	3	10	3	10
Footprint (floor area) [m^2]	50	700	3150	1050	5250
Roof area [m^2]	75	700	3150	1050	5250
Total wall area including windows [m^2]	108	1440	13500	1530	14100
Used (heated/cooled) building area [m^2]	113	1890	28350	2835	47250
Window area - East [m^2]	6.8	169	2531	306	2820
Window area - South [m^2]	6.8	169	2531	306	2820
Window area - West [m^2]	6.8	169	2531	306	2820
Window area - North [m^2]	6.8	169	2531	306	2820
Glass/floor	27%	32%	32%	39%	22%
Glass/façade	25%	47%	75%	80%	80%

Table 5 Assumed floor area distribution (x million m^2) over the building ages, types and country clusters in **2020**.

	Total	Dwelling	Apartment building small	Apartment building large	Non-residential small	Non-residential large
North						
<1975 non-refurbished	140	64	24	13	15	24
<1975 refurbished	560	257	96	52	58	98
1975-1990	214	98	36	20	22	38
1991-2002	180	83	31	17	19	31
2002-2006	91	41	16	8	9	16
2006-2020	128	59	22	12	13	22
Central maritime						
<1975 non-refurbished	1746	878	238	128	149	352
<1975 refurbished	4074	2050	556	300	347	821
1975-1990	1609	810	220	118	137	324
1991-2002	1214	610	166	89	103	245
2002-2006	358	180	49	26	31	72
2006-2020	2334	1174	319	172	199	471
Central continental						
<1975 non-refurbished	999	503	136	73	85	201
<1975 refurbished	2331	1173	318	171	198	470
1975-1990	921	463	126	68	78	186
1991-2002	694	349	95	51	59	140
2002-2006	205	103	28	15	17	41
2006-2020	1229	618	168	90	105	248
South						
<1975 non-refurbished	1503	577	371	200	154	201
<1975 refurbished	1503	577	371	200	154	201
1975-1990	1877	722	463	250	192	250
1991-2002	1269	488	313	169	130	169
2002-2006	255	98	63	34	26	34
2006-2020	811	312	200	108	83	108
Baltics						
<1975 non-refurbished	156	66	29	24	14	24
<1975 refurbished	39	16	7	6	3	6
1975-1990	85	35	16	13	8	13
1991-2002	14	6	3	2	1	2
2002-2006	4	1,9	0,8	0,7	0,4	0,6
2006-2020	56	24	10	9	5	9
Central						
<1975 non-refurbished	1032	437	118	201	127	149
<1975 refurbished	244	103	28	47	30	35
1975-1990	580	243	67	115	71	84
1991-2002	200	80	25	43	24	28
2002-2006	60	24	8	13	7	8
2006-2020	399	167	46	79	49	57
Romania & Bulgaria						
<1975 non-refurbished	447	215	37	70	56	70
<1975 refurbished	112	54	9	17	14	17
1975-1990	247	119	20	39	30	39
1991-2002	48	24	4	8	6	8
2002-2006	14	7	1	2	2	2
2006-2020	383	184	31	60	48	60

Table 6 Assumed floor area distribution (x million m²) over the building ages, types and country clusters in **2030**.

	Total	Dwelling	Apartment building small	Apartment building large	Non-residential small	Non-residential large
North						
<1975 non-refurbished	137	63	23	13	14	24
<1975 refurbished	549	252	94	51	57	96
1975-1990	210	96	35	19	22	37
1991-2002	177	81	30	16	18	31
2002-2006	89	41	15	8	9	15
2006-2020	125	57	21	12	13	22
2020-2030	101	47	17	9	11	18
Central maritime						
<1975 non-refurbished	1711	861	234	126	146	345
<1975 refurbished	3993	2009	545	294	340	805
1975-1990	1577	794	216	116	134	318
1991-2002	1189	598	163	87	101	240
2002-2006	351	176	48	26	30	71
2006-2020	2288	1151	313	168	195	461
2020-2030	2109	1061	288	155	180	425
Central continental						
<1975 non-refurbished	979	493	134	72	83	197
<1975 refurbished	2285	1150	312	168	194	461
1975-1990	903	454	123	66	77	182
1991-2002	681	342	93	50	58	137
2002-2006	201	101	27	15	17	41
2006-2020	1205	606	165	89	103	243
2020-2030	1092	550	149	80	93	220
South						
<1975 non-refurbished	1473	566	364	196	151	197
<1975 refurbished	1473	566	364	196	151	197
1975-1990	1840	707	454	245	189	245
1991-2002	1244	478	307	166	127	166
2002-2006	250	96	62	33	26	33
2006-2020	795	305	196	106	81	106
2020-2030	655	252	162	87	67	87
Baltics						
<1975 non-refurbished	152	64	28	24	13	23
<1975 refurbished	38	16	7	6	3	6
1975-1990	83	34	16	13	7	13
1991-2002	14	6	3	2	1	2
2002-2006	4	1,8	0,8	0,7	0,4	0,6
2006-2020	55	23	10	9	5	8
2020-2030	48	20	9	7	4	7
Central						
<1975 non-refurbished	1012	428	116	197	125	146
<1975 refurbished	239	101	27	47	29	35
1975-1990	568	238	65	113	69	82
1991-2002	196	78	25	42	24	27
2002-2006	59	23	7	13	7	8
2006-2020	391	164	45	77	48	56
2020-2030	340	143	39	67	42	49
Romania & Bulgaria						
<1975 non-refurbished	439	211	36	68	55	68
<1975 refurbished	110	53	9	17	14	17
1975-1990	242	116	19	38	30	38
1991-2002	47	23	4	7	6	7
2002-2006	14	7	1	2	2	2
2006-2020	375	181	31	59	47	59
2020-2030	396	191	32	62	49	62

Table 7 2050 floor area distribution (x million m^2) over the building ages, types and country clusters.

	Total	Dwelling	Apartment building small	Apartment building large	Non-residential small	Non-residential large
North						
<1975 non-refurbished	132	60	23	12	14	23
<1975 refurbished	528	242	90	49	55	92
1975-1990	202	93	34	19	21	35
1991-2002	170	78	29	16	18	30
2002-2006	85	39	15	8	9	15
2006-2020	120	55	20	11	13	21
2020-2030	101	47	17	9	11	18
2030-2050	230	106	39	21	24	40
Central maritime						
<1975 non-refurbished	1644	827	225	121	140	332
<1975 refurbished	3836	1930	524	282	326	774
1975-1990	1515	763	207	111	129	305
1991-2002	1143	575	156	84	97	230
2002-2006	337	170	46	25	29	68
2006-2020	2198	1106	300	162	187	443
2020-2030	2109	1061	288	155	180	425
2030-2050	5253	2643	718	386	447	1059
Central continental						
<1975 non-refurbished	941	473	128	69	80	190
<1975 refurbished	2195	1105	300	161	187	443
1975-1990	867	436	119	64	74	175
1991-2002	654	329	90	48	56	132
2002-2006	193	97	26	14	16	39
2006-2020	1157	582	158	85	99	233
2020-2030	1092	550	149	80	93	220
2030-2050	2687	1352	367	197	229	542
South						
<1975 non-refurbished	1415	544	350	188	145	189
<1975 refurbished	1415	544	350	188	145	189
1975-1990	1768	679	436	235	181	236
1991-2002	1195	460	295	159	122	159
2002-2006	240	92	59	32	25	32
2006-2020	763	293	188	102	78	102
2020-2030	655	252	162	87	67	87
2030-2050	1505	578	372	200	154	201
Baltics						
<1975 non-refurbished	147	62	27	23	13	22
<1975 refurbished	37	15	7	6	3	6
1975-1990	80	33	15	12	7	12
1991-2002	14	6	2	2	1	2
2002-2006	4	1,8	0,7	0,6	0,4	0,6
2006-2020	53	22	10	8	5	8
2020-2030	48	20	9	7	4	7
2030-2050	115	48	21	18	10	17
Central						
<1975 non-refurbished	972	411	111	189	120	141
<1975 refurbished	229	97	26	45	28	33
1975-1990	546	229	63	109	66	79
1991-2002	188	75	24	40	23	26
2002-2006	57	23	7	12	7	8
2006-2020	375	157	44	74	46	54
2020-2030	340	143	39	67	42	49
2030-2050	812	340	94	161	99	117
Romania & Bulgaria						
<1975 non-refurbished	421	202	35	66	53	66
<1975 refurbished	105	51	9	16	13	16
1975-1990	232	112	19	37	28	37
1991-2002	45	22	3	7	6	7
2002-2006	14	7	1	2	2	2
2006-2020	361	174	29	56	45	56
2020-2030	396	191	32	62	49	62
2030-2050	1091	525	89	171	136	171

2.3.1 Definition of building insulation and window properties

Thermal insulation of buildings depends on the age of the building and on the climate and so do the U-value and the g-value of the windows. Table 8 presents the U-values and g-values used for the reference calculations, i.e. without application of high performance glazing. Most insulation values have been derived from literature ([7],[8],[9],[10] and [11]).

Glazing properties for high performance glazing and reference cases are provided by GLASS FOR EUROPE clusters (Table 9 and annex 1).

Table 8 Heat transfer coefficient for roofs, façades, floors and windows as well as the window g-value for different building ages and country clusters.

	< 1975 non-refurb	**< 1975 refurb**	**1975-1990**	**1991-2002**	**2002-2006**	**2006-2020**	**2020-2030**	**2030-2050**
North								
U_{roof} [W/(m²K)]	0,50	0,20	0,20	0,15	0,15	0,14	0,13	0,12
U_{facade} [W/(m²K)]	0,50	0,30	0,30	0,20	0,18	0,17	0,16	0,14
U_{floor} [W/(m²K)]	0,50	0,20	0,20	0,15	0,18	0,17	0,16	0,14
U_{window} [W/(m²K)]	3,50	3,27	2,59	2,25	1,93	1,45	1,11	0,88
g_{window} [-]	0,58	0,57	0,51	0,48	0,45	0,41	0,36	0,36
Central maritime								
U_{roof} [W/(m²K)]	1,50	0,50	0,50	0,40	0,25	0,23	0,21	0,19
U_{facade} [W/(m²K)]	1,50	1,00	1,00	0,50	0,41	0,38	0,32	0,25
U_{floor} [W/(m²K)]	1,20	0,80	0,80	0,50	0,44	0,41	0,34	0,25
U_{window} [W/(m²K)]	4,66	4,08	3,85	3,82	3,10	1,70	1,35	1,00
g_{window} [-]	0,61	0,59	0,58	0,57	0,53	0,45	0,36	0,36
Central continental								
U_{roof} [W/(m²K)]	1,50	0,50	0,50	0,40	0,25	0,23	0,21	0,19
U_{facade} [W/(m²K)]	1,50	1,00	1,00	0,50	0,41	0,38	0,32	0,25
U_{floor} [W/(m²K)]	1,20	0,80	0,80	0,50	0,44	0,41	0,35	0,25
U_{window} [W/(m²K)]	4,95	4,14	2,90	2,59	2,28	1,82	1,23	0,96
g_{window} [-]	0,62	0,59	0,51	0,51	0,49	0,45	0,36	0,36
South								
U_{roof} [W/(m²K)]	3,40	1,00	0,80	0,50	0,50	0,43	0,41	0,35
U_{facade} [W/(m²K)]	2,60	1,40	1,20	0,60	0,60	0,48	0,45	0,30
U_{floor} [W/(m²K)]	3,40	1,00	0,80	0,55	0,55	0,48	0,45	0,30
U_{window} [W/(m²K)]	5,24	4,31	4,08	4,28	3,25	2,62	1,59	1,28
g_{window} [-]	0,63	0,60	0,59	0,60	0,53	0,50	0,36	0,36
Baltics								
U_{roof} [W/(m²K)]	0,70	0,62	0,62	0,62	0,19	0,17	0,15	0,12
U_{facade} [W/(m²K)]	0,90	0,78	0,78	0,33	0,27	0,23	0,22	0,20
U_{floor} [W/(m²K)]	0,70	0,64	0,64	0,34	0,26	0,25	0,23	0,20
U_{window} [W/(m²K)]	4,66	4,08	3,85	3,82	3,10	1,90	1,27	0,96
g_{window} [-]	0,61	0,59	0,52	0,51	0,53	0,47	0,36	0,36

Table continues on next page

Table 8 continued

	< 1975 non-refurb	< 1975 refurb	1975-1990	1991-2002	2002-2006	2006-2020	2020-2030	2030-2050
Central								
U_{roof} [W/(m^{2}K)]	1,40	0,70	0,70	0,70	0,38	0,23	0,21	0,19
U_{facade} [W/(m^{2}K)]	1,50	1,00	1,00	1,00	0,55	0,34	0,32	0,25
U_{floor} [W/(m^{2}K)]	1,40	0,90	0,90	0,90	0,68	0,44	0,41	0,31
U_{window} [W/(m^{2}K)]	4,66	4,31	4,08	3,86	3,17	2,26	1,43	1,12
g_{window} [-]	0,61	0,60	0,59	0,58	0,54	0,49	0,36	0,36
Romania and Bulgaria								
U_{roof} [W/(m^{2}K)]	1,20	1,20	1,20	0,90	0,30	0,28	0,21	0,19
U_{facade} [W/(m^{2}K)]	1,60	1,40	1,40	1,20	0,70	0,58	0,32	0,23
U_{floor} [W/(m^{2}K)]	1,20	1,00	1,00	0,78	0,75	0,53	0,41	0,31
U_{window} [W/(m^{2}K)]	5,24	4,78	4,31	4,02	3,38	2,64	1,59	1,28
g_{window} [-]	0,63	0,61	0,60	0,58	0,56	0,52	0,36	0,36

Table 9 U- and g-values for high performance glazing for residential and non residential buildings per country cluster for the period 2020-2030 and the period 2030-2050.

REPLACED 2020-2030	Residential renovation		Residential new		Non Residential renovation + new	
Country cluster	U_g	g_g	U_g	g_g	U_g	g_g
North	0,57	0,44	0,55	0,44	0,64	0,26
Central maritime	0,76	0,45	0,72	0,45	0,97	0,3
Central continental	0,64	0,44	0,56	0,44	0,67	0,26
South	1,07	0,37	1,02	0,32	1,02	0,32
Baltics	0,61	0,44	0,56	0,44	0,66	0,26
Central	0,68	0,44	0,64	0,44	0,67	0,26
Bulgaria & Romania	1,07	0,37	1,02	0,32	1,02	0,32

REPLACED 2030-2050	Residential renovation + new		Non Residential renovation + new	
Country cluster	U_g	g_g	U_g	g_g
North	0,29	0,49	0,4	0,3
Central maritime	0,36	0,56	0,4	0,3
Central continental	0,29	0,49	0,4	0,3
South	0,5	0,2	0,5	0,2
Baltics	0,29	0,49	0,4	0,3
Central	0,39	0,54	0,5	0,2
Bulgaria & Romania	0,4	0,3	0,5	0,2

2.3.2 Definition of high performance window properties

The glazing properties of table 9 are used to calculate the properties of the window, i.e. including the frame as described in chapter 2.1.4. where a frame fraction (A_f/A_w) of 0.20 and a perimeter length of 2.5 meter per square meter window are assumed. A frame U-value (U_f) of 1.6 W/(m^2.K) is assumed for all buildings applied with high performance glazing or built after 2020. For all other buildings a frame U-value of 2.25 W/(m^2.K) is assumed. A linear thermal transmittance (ψ) of 0.03 W/(m·K) is assumed for windows applied after 2030 including high performance glazing. For all other cases A linear thermal transmittance of 0.06 W/(m·K) is assumed. In table 10 the computed window properties are provided .

Table 10: U- and g-values windows for high performance glazing for residential and non residential per country cluster for the period 2020-2030 and the period 2030-2050.

REPLACED 2020-2030	Residential renovation		Residential new		Non Residential renovation + new	
	U_w	g_w	U_w	g_w	U_w	g_w
North	0,93	0,32	0,91	0,32	0,98	0,19
Central maritime	1,08	0,32	1,05	0,32	1,25	0,22
Central continental	0,98	0,32	0,92	0,32	1,01	0,19
South	1,33	0,27	1,29	0,23	1,29	0,23
Baltics	0,96	0,32	0,92	0,32	1	0,19
Central	1,01	0,32	0,98	0,32	1,01	0,19
Bulgaria & Romania	1,33	0,27	1,29	0,23	1,29	0,23

REPLACED 2030-2050	Residential renovation + new		Non Residential renovation + new	
	U_w	g_w	U_w	g_w
North	0,63	0,35	0,72	0,22
Central maritime	0,68	0,4	0,72	0,22
Central continental	0,63	0,35	0,72	0,22
South	0,8	0,14	0,8	0,14
Baltics	0,63	0,35	0,72	0,22
Central	0,71	0,39	0,8	0,14
Bulgaria & Romania	0,72	0,22	0,8	0,14

2.3.3 Definition of internal climate control and building occupancy

Heating and cooling loads of buildings depend on control systems for the internal climate and their settings. Internal climate for the calculations is controlled by set point temperatures for heating and cooling and ventilation rates as follows:

– set point for heating: 19°C;
– set point for cooling: 24°C;

- ventilation regime:
  - for dwellings and small apartment buildings: natural ventilation;
  - for large apartment buildings and small non-residential buildings: forced ventilation;
  - for large non-residential buildings and all buildings built from 2020 on: balanced ventilation;
- ventilation rate:
  - for natural and forced ventilation for residential buildings: 0.6 x used building area in litres/s;
  - for natural and forced ventilation for non-residential buildings: 0.65 x used building area in litres/s;
  - for balanced ventilation: 0.65 x (1 – effective efficiency of heat recovery) x used building area in litres/s, where efficiency of heat recovery = 0.70.

The internal heat gain depends on the building occupancy as follows:
- for residential buildings: 6 W/m^2;
- for non-residential buildings: 10.8 W/m^2.

2.3.4 *Definition of conversion of energy for heating and cooling into CO_2 production*

The calculation core of the tool delivers energy for heating and cooling of the many combinations. Final processing provides the energy savings.
Two conversions are needed to derive CO_2 savings from the energy savings, i.e. efficiency of heating and cooling systems and CO_2 production related to heating and cooling:

$$\Delta M_{CO2} = \Delta Q_{nd} \cdot (CO_2 \text{ production per unit of energy}) / \eta_{sys} \quad (9)$$

where:

η_{sys} is the efficiency of the heating or cooling system;
ΔQ_{nd} is the energy savings for heating or cooling.

System efficiency for the calculations has been defined as follows:
- for heating efficiency 0.90 is assumed (label A [12]) for all periods except for 2050, 1.25 is assumed (label A++ [12]);
- for cooling systems a coefficient of performance (COP) of 3.4 is assumed (label A[13]) except for 2050, 4.6 is assumed (label A++[13]).

CO_2 production related to heating and cooling differs per country due to variations in the mix of primary energy sources used for heat and electricity production. Therefore the CO_2 production is computed per member state. For this the energy for heating and cooling per country cluster are divided per cluster proportionally to the number of inhabitants per country. Table 12 presents the conversion from energy for heating and cooling into CO_2 following EU Reference Scenario 2016 ([15]). Heating systems are assumed present in all buildings. Table 11 presents the cooling penetration rates per period, country cluster and building type ([14]).

Table 11: Cooling system penetration rates per period and region

Country cluster	2020-2030		2030-2050	
	Residential	Non residential	Residential	Non residential
North	10%	50%	30%	70%
Central maritime	20%	65%	45%	85%
Central continental	20%	65%	45%	85%
South	40%	80%	70%	90%
Baltics	15%	50%	30%	80%
Central	15%	55%	40%	80%
Romania – Bulgaria	15%	55%	45%	80%

Table 12 Conversion from energy demand for heating and cooling into CO_2 production for different country clusters and countries

	2020		2030		2050	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
	kg CO_2/MJ	kg CO_2/MJ	kg CO_2/MJ	kg CO_2/MJ	kg CO_2/MJ	kg CO_2/MJ
North						
Finland	0,0083	0,033	0,0067	0,033	0,0052	0,011
Sweden	0,0024	0,008	0,0021	0,008	0,0017	0,006
Central maritime						
Belgium	0,0416	0,056	0,0407	0,056	0,0376	0,050
Denmark	0,0146	0,025	0,0129	0,025	0,0121	0,008
Ireland	0,0467	0,078	0,0428	0,078	0,0333	0,036
Luxemburg	0,0407	0,067	0,0388	0,067	0,0347	0,067
The Netherlands	0,0379	0,067	0,0354	0,067	0,0323	0,044
United Kingdom	0,0373	0,031	0,0355	0,031	0,0310	0,022
France	0,0241	0,003	0,0241	0,003	0,0205	0,006
Central maritime					\	
Austria	0,0206	0,036	0,0188	0,036	0,0168	0,022
Germany	0,0356	0,103	0,0330	0,103	0,0302	0,039
South						
Cyprus	0,0200	0,064	0,0158	0,064	0,0084	0,050
Greece	0,0211	0,094	0,0190	0,094	0,0150	0,019
Italy	0,0335	0,067	0,0327	0,067	0,0284	0,031
Malta	0,0181	0,078	0,0158	0,078	0,0126	0,072
Portugal	0,0175	0,014	0,0125	0,014	0,0154	0,006
Spain	0,0218	0,036	0,0203	0,036	0,0177	0,014
Baltics						
Lithuania	0,0123	0,019	0,0115	0,019	0,0090	0,014
Latvia	0,0120	0,028	0,0119	0,028	0,0116	0,017
Estonia	0,0092	0,142	0,0082	0,142	0,0077	0,042
Central						
Poland	0,0374	0,139	0,0314	0,139	0,0242	0,028
Czech rep	0,0272	0,119	0,0257	0,119	0,0215	0,022
Hungary	0,0322	0,025	0,0320	0,025	0,0288	0,019
Slovakia	0,0305	0,025	0,0285	0,025	0,0262	0,014
Slovenia	0,0186	0,075	0,0162	0,075	0,0142	0,011
Croatia	0,0244	0,044	0,0248	0,044	0,0240	0,022
Rumania Bulgaria						
Rumania	0,0237	0,039	0,0236	0,039	0,0220	0,011
Bulgaria	0,0085	0,081	0,0064	0,081	0,0047	0,000

3 Five scenarios for savings of energy and CO_2 by high performance glazing

3.1 Introduction: explanation of the presented savings

Sets of two calculations are used to determine the potential energy savings:

– in the first calculation, the annual heating and cooling energy is calculated for the building with reference glazing, which is already present in existing buildings or is expected to be applied in future buildings;
– in the second calculation, the annual heating and cooling energy is calculated for the same building with high performance glazing. The properties for high performance glazing are provided by Glass for Europe for the different buildings, regions, building periods and horizons [Annex 1].

The difference of the annual energy requirements resulting from the two calculations yields the potential annual energy savings for heating and cooling. Subsequently, potential CO_2 reductions are derived from the annual energy savings and the assumed country and period specific carbon intensities.

The potential annual energy savings and CO_2 reductions are calculated for five scenarios of penetration of high-performance glazing:

Scenario 1: application of high performance glazing in 1% of the buildings in 2020;

Scenario 2: application of high performance glazing in 1% of the buildings in 2030;

Scenario 3: application of high performance glazing in 10% of the buildings between 2020 and 2030, simulating the impact of a 1% per year window renovation rate over 10 years;

Scenario 4: application of high performance glazing in all buildings in 2030;

Scenario 5: application of high performance glazing in all buildings in 2050.

Scenarios 1, 2 and 3 focus on renovation of existing buildings. Scenarios 4 and 5 represent the savings induced by high-performance glazing being installed in both renovated buildings and new buildings.

For all scenario's, boundary conditions as for instance system efficiencies, air conditioning integration rates, demolition rates and carbon intensities are taken into account for the specified periods. Energy savings have been converted into CO_2 savings using the carbon intensity provided in Table 12.

3.2 Application of high performance glazing in 1% of the buildings in 2020

In scenario 1, high performance glazing, as defined for 2020 - 2030 (Annex 1), is applied on renovation buildings built until 2002, with a total floor area of 1% of the total floor area of all buildings in 2020. The 1% is evenly distributed over all building types, building periods and regions.
The annual energy savings for heating and cooling and CO_2 reductions are calculated using boundary conditions for 2030 provided in Chapter 2. Table 13 presents the results for Scenario 1.

Table 13 Annual energy savings for heating and cooling and CO_2 reduction for Scenario 1.

SC1: 2020 1%	**Energy savings** [kToe]			**CO_2 reduction** [kTon]		
	Total	Heating	Cooling	Total	Heating	Cooling
North	**42,6**	**41,8**	**0,8**	**8,61**	**7,99**	**0,62**
- Finland	15,6	15,3	0,3	5,75	5,32	0,43
- Sweden	27,0	26,4	0,5	2,86	2,67	0,19
Central maritime	**315,4**	**310,2**	**5,2**	**421,90**	**416,16**	**5,73**
- Belgium	20,7	20,3	0,3	36,20	35,41	0,79
- Denmark	10,9	10,7	0,2	6,72	6,54	0,19
- Ireland	8,1	8,0	0,1	15,98	15,54	0,43
- Luxemburg	0,9	0,9	0,0	1,62	1,58	0,04
- Netherlands	32,8	32,3	0,5	52,75	51,24	1,51
- United Kingdom	120,7	118,7	2,0	187,82	185,28	2,54
- France	121,3	119,3	2,0	120,80	120,57	0,23
Central continental	**241,1**	**237,3**	**3,8**	**355,75**	**340,54**	**15,20**
- Austria	21,8	21,5	0,3	19,02	18,51	0,51
- Germany	219,3	215,9	3,4	336,73	322,03	14,69
South	**89,6**	**57,6**	**32,0**	**137,77**	**65,04**	**72,73**
- Cyprus	0,6	0,4	0,2	0,88	0,32	0,57
- Greece	7,9	5,1	2,8	15,66	4,49	11,17
- Italy	43,1	27,7	15,4	81,72	38,84	42,88
- Malta	0,3	0,2	0,1	0,49	0,14	0,34
- Portugal	7,9	5,1	2,8	5,32	3,69	1,63
- Spain	29,9	19,2	10,7	33,70	17,56	16,14
Baltics	**24,2**	**24,1**	**0,1**	**11,99**	**11,71**	**0,28**
- Lithuania	11,9	11,8	0,1	6,15	6,09	0,06
- Latvia	7,8	7,8	0,0	3,95	3,89	0,06
- Estonia	4,5	4,5	0,0	1,89	1,73	0,16
Central	**126,6**	**124,9**	**1,6**	**181,42**	**174,30**	**7,12**
- Poland	69,1	68,2	0,9	111,95	106,73	5,22
- Czech rep	18,5	18,2	0,2	21,91	20,71	1,20
- Hungary	18,3	18,1	0,2	24,61	24,36	0,25
- Slovakia	9,7	9,6	0,1	12,33	12,20	0,13
- Slovenia	3,6	3,6	0,0	2,92	2,77	0,15
- Croatia	7,5	7,4	0,1	7,70	7,52	0,18
Romania and Bulgaria	**62,6**	**61,8**	**0,8**	**53,26**	**51,66**	**1,60**

- Rumania	47,2	46,7	0,6	47,25	46,29	0,96
- Bulgaria	15,4	15,2	0,2	6,01	5,37	0,64
EU28	**902**	**858**	**44**	**1171**	**1067**	**103**

3.3 Application of high performance glazing in 1% of the buildings in 2030

In scenario 2, high performance glazing, as defined for 2030-2050 (Annex 1), is applied on renovation buildings built until 2002, with an expected total floor area of 1% of the total floor area of all buildings in 2030. The 1% is evenly distributed over all building types, building periods and regions. The annual energy savings for heating and cooling and CO_2 reductions are calculated using boundary conditions for 2050 provided in Chapter 2. Table 14 presents the results for Scenario 2.

Table 14 Annual energy savings for heating and cooling and CO_2 reduction for Scenario 2

SC2: 2030 1%	**Energy savings** [kToe]			**CO_2 reduction** [kTon]		
	Total	Heating	Cooling	Total	Heating	Cooling
North	**55,1**	**54,3**	**0,8**	**9,12**	**8,56**	**0,56**
- Finland	20,2	19,9	0,3	5,94	5,55	0,39
- Sweden	34,9	34,4	0,5	3,17	3,00	0,17
Central maritime	**470,7**	**466,6**	**4,1**	**607,59**	**603,01**	**4,58**
- Belgium	30,9	30,6	0,3	52,81	52,18	0,63
- Denmark	16,2	16,1	0,1	8,86	8,71	0,15
- Ireland	12,1	12,0	0,1	21,78	21,43	0,35
- Luxemburg	1,4	1,4	0,0	2,31	2,27	0,03
- Netherlands	49,0	48,6	0,4	73,25	72,04	1,20
- United Kingdom	180,2	178,6	1,6	267,39	265,36	2,03
- France	181,0	179,4	1,6	181,21	181,02	0,19
Central continental	**341,8**	**338,1**	**3,8**	**464,15**	**448,82**	**15,34**
- Austria	30,9	30,6	0,3	24,52	24,00	0,52
- Germany	310,9	307,5	3,4	439,64	424,82	14,82
South	**107,5**	**51,4**	**56,1**	**182,27**	**54,74**	**127,53**
- Cyprus	0,7	0,3	0,4	1,22	0,22	0,99
- Greece	9,5	4,5	5,0	23,20	3,62	19,58
- Italy	51,6	24,7	26,9	109,03	33,84	75,19
- Malta	0,4	0,2	0,2	0,72	0,11	0,60
- Portugal	9,4	4,5	4,9	5,21	2,35	2,86
- Spain	35,9	17,2	18,7	42,90	14,59	28,30
Baltics	**31,8**	**31,7**	**0,1**	**14,87**	**14,61**	**0,26**
- Lithuania	15,6	15,6	0,1	7,55	7,50	0,06
- Latvia	10,3	10,2	0,0	5,13	5,08	0,05
- Estonia	5,9	5,9	0,0	2,18	2,03	0,15
Central	**166,5**	**164,5**	**2,0**	**212,79**	**203,96**	**8,83**
- Poland	90,9	89,8	1,1	124,54	118,07	6,47
- Czech rep	24,3	24,0	0,3	27,27	25,79	1,49
- Hungary	24,1	23,8	0,3	32,16	31,85	0,31
- Slovakia	12,7	12,6	0,2	15,20	15,04	0,16
- Slovenia	4,7	4,7	0,1	3,36	3,17	0,18

- Croatia	9,8	9,7	0,1	10,26	10,04	0,22
Romania and Bulgaria	**97,9**	**96,2**	**1,7**	**81,58**	**78,12**	**3,47**
- Rumania	73,9	72,6	1,3	73,90	71,83	2,07
- Bulgaria	24,0	23,6	0,4	7,69	6,29	1,40
EU28	**1271**	**1203**	**69**	**1572**	**1412**	**161**

3.4 Application of high performance glazing in 10% of the buildings between 2020 and 2030

In scenario 3, high performance glazing is applied in 10% of the buildings between 2020 and 2030, simulating the impact of a 1% per year window renovation rate over 10 years. High performance glazing, as defined for 2020 - 2030 (Annex 1), is applied on renovation buildings built until 2002. The 1% is evenly distributed over all building types, building periods and regions. The annual energy savings for heating and cooling and CO2 reductions are calculated using boundary conditions for 2030 provided in Chapter 2. Table 15 presents the results for Scenario 3. The total computed accumulated energy savings over the 10 year period are 49.8 MToe (47.2 MToe for heating and 2.6 MToe for cooling).

Table 15 Annual energy savings for heating and cooling and matching CO_2 reduction for Scenario 3'

SC3: 2020-2030 10%		**Energy savings**						**CO_2 reduction**		
	Total		Heating		Cooling		Total		Heating	Cooling
	[kToe]	[%]	[kToe]	[%]	[kToe]	[%]	[kTon]	[%]	[kTon]	[kTon]
North	**427**	**3,9**	**418**	**4,2**	**9,1**	**1,1**	**80**	**3,4**	**73**	**7**
- Finland	157	3,9	153	4,2	3,3	1,1	53	3,3	48	5
- Sweden	270	3,9	264	4,2	5,8	1,1	27	3,5	25	2
Central maritime	**3160**	**4,0**	**3102**	**4,2**	**57,8**	**1,2**	**4149**	**4,0**	**4085**	**64**
- Belgium	207	4,0	203	4,2	3,8	1,2	359	3,9	351	9
- Denmark	109	4,0	107	4,2	2,0	1,2	64	3,9	62	2
- Ireland	81	4,0	80	4,2	1,5	1,2	154	3,9	149	5
- Luxemburg	9	4,0	9	4,2	0,2	1,2	16	3,9	15	0
- Netherlands	329	4,0	323	4,2	6,0	1,2	512	3,9	496	17
- United Kingdom	1209	4,0	1187	4,2	22,1	1,2	1837	4,0	1808	28
- France	1215	4,0	1193	4,2	22,2	1,2	1207	4,2	1205	3
Central continental	**2415**	**3,6**	**2373**	**3,7**	**41,7**	**1,4**	**3447**	**3,4**	**3278**	**169**
- Austria	218	3,6	215	3,7	3,8	1,4	182	3,5	177	6
- Germany	2197	3,6	2159	3,7	38,0	1,4	3265	3,4	3101	163
South	**926**	**2,1**	**576**	**2,5**	**349,2**	**1,7**	**1426**	**2,0**	**632**	**794**
- Cyprus	6	2,1	4	2,5	2,3	1,7	9	1,9	3	6
- Greece	82	2,1	51	2,5	30,8	1,7	165	1,8	43	122
- Italy	445	2,1	277	2,5	167,7	1,7	852	2,0	384	468
- Malta	3	2,1	2	2,5	1,2	1,7	5	1,8	1	4
- Portugal	81	2,1	51	2,5	30,6	1,7	49	2,1	32	18
- Spain	309	2,1	192	2,5	116,6	1,7	346	2,0	170	176
Baltics	**242**	**4,5**	**241**	**4,6**	**1,7**	**0,9**	**117**	**4,1**	**114**	**3**
- Lithuania	119	4,5	118	4,6	0,8	0,9	60	4,4	59	1
- Latvia	78	4,5	78	4,6	0,5	0,9	39	4,3	39	1
- Estonia	45	4,5	45	4,6	0,3	0,9	18	3,2	16	2
Central	**1268**	**3,9**	**1249**	**4,1**	**18,4**	**1,0**	**1726**	**3,6**	**1646**	**80**
- Poland	692	3,9	682	4,1	10,1	1,0	1041	3,5	982	59
- Czech rep	185	3,9	182	4,1	2,7	1,0	215	3,4	201	13
- Hungary	183	3,9	181	4,1	2,7	1,0	246	3,9	243	3
- Slovakia	97	3,9	96	4,1	1,4	1,0	120	3,9	118	1
- Slovenia	36	3,9	36	4,1	0,5	1,0	28	3,4	26	2
- Croatia	75	3,9	74	4,1	1,1	1,0	78	3,8	76	2
Romania and Bulgaria	**627**	**3,6**	**618**	**3,8**	**9,0**	**0,9**	**528**	**3,4**	**509**	**18**
- Rumania	473	3,6	467	3,8	6,8	0,9	473	3,5	462	11
- Bulgaria	154	3,6	152	3,8	2,2	0,9	54	2,7	47	7
EU28	**9065**	**3,5**	**8578**	**3,8**	**487**	**1,5**	**11473**	**3,3**	**10338**	**1135**

3.5 Application of high performance glazing in 100% of the buildings in 2030

In scenario 4 high performance glazing, as defined for 2020 - 2030 (Annex 1), is assumed to be applied on all buildings in 2030. The annual energy savings for heating and cooling and CO_2 reductions are calculated using boundary conditions for 2030 provided in Chapter 2. The results are presented in table 16.

Table 16 Annual energy savings for heating and cooling and matching CO_2 reduction for scenario 4

SC4: 2030 100%	**Energy savings**						**CO_2 reduction**			
	Total		Heating		Cooling		Total		Heating	Cooling
	[kToe]	[%]	[kToe]	[%]	[kToe]	[%]	[kTon]	[%]	[kTon]	[kTon]
North	**3713**	**34**	**3615**	**36**	**98**	**12**	**641**	**29**	**570**	**72**
- Finland	1363	34	1327	36	36	12	420	29	370	50
- Sweden	2350	34	2288	36	62	12	222	30	200	22
Central maritime	**25381**	**32**	**24643**	**33**	**737**	**14**	**32663**	**32**	**31848**	**815**
- Belgium	1664	32	1615	33	48	14	2868	31	2756	112
- Denmark	874	32	848	33	25	14	486	31	460	27
- Ireland	651	32	632	33	19	14	1193	31	1132	62
- Luxemburg	76	32	74	33	2	14	126	31	120	6
- Netherlands	2643	32	2567	33	77	14	4019	31	3805	214
- United Kingdom	9715	32	9433	33	282	14	14376	32	14015	361
- France	9758	32	9474	33	283	14	9594	33	9561	33
Central continental	**19787**	**29**	**19269**	**29**	**517**	**17**	**27679**	**28**	**25583**	**2096**
- Austria	1789	29	1742	29	47	17	1439	29	1368	71
- Germany	17998	29	17527	29	471	17	26240	28	24215	2025
South	**8606**	**19**	**4840**	**21**	**3766**	**18**	**13715**	**19**	**5151**	**8565**
- Cyprus	57	19	32	21	25	18	88	18	21	67
- Greece	760	19	427	21	333	18	1655	18	340	1315
- Italy	4134	19	2325	21	1809	18	8234	19	3184	5050
- Malta	28	19	16	21	12	18	51	18	11	41
- Portugal	754	19	424	21	330	18	413	19	221	192
- Spain	2873	19	1615	21	1257	18	3274	19	1373	1901
Baltics	**2091**	**39**	**2070**	**40**	**21**	**10**	**993**	**36**	**954**	**39**
- Lithuania	1026	39	1016	40	10	10	498	38	490	8
- Latvia	675	39	668	40	7	10	340	37	332	8
- Estonia	390	39	386	40	4	10	156	28	132	23
Central	**11126**	**34**	**10907**	**35**	**219**	**11**	**14474**	**31**	**13526**	**949**
- Poland	6073	34	5953	35	120	11	8525	30	7830	695
- Czech rep	1622	34	1590	35	32	11	1870	30	1710	160
- Hungary	1608	34	1576	35	32	11	2145	34	2112	33
- Slovakia	852	34	835	35	17	11	1015	34	997	18
- Slovenia	317	34	311	35	6	11	230	30	211	20
- Croatia	655	34	642	35	13	11	690	33	666	24
Romania and Bulgaria	**4810**	**27**	**4683**	**28**	**127**	**12**	**4063**	**26**	**3803**	**261**
- Rumania	3630	27	3534	28	96	12	3652	26	3497	156
- Bulgaria	1180	27	1149	28	31	12	411	21	306	105
EU28	**75514**	**29**	**70028**	**31**	**5486**	**16**	**94230**	**28**	**81434**	**12796**

3.6 Application of high performance glazing in 100% of the buildings in 2050

In scenario 5 high performance glazing, as defined for 2030 - 2050 (Annex 1), is assumed to be applied on all buildings in 2050. The annual energy savings for heating and cooling and CO_2 reductions are calculated using boundary conditions for 2050 provided in Chapter 2. The results are presented in table 17.

Table 17 Annual energy savings for heating and cooling and matching CO_2 reduction for scenario 5

SC5: 2050 100%	**Energy savings**						**CO_2 reduction**			
	Total		Heating		Cooling		Total		Heating	Cooling
	[kToe]	[%]	[kToe]	[%]	[kToe]	[%]	[kTon]	[%]	[kTon]	[kTon]
North	**3259**	**43**	**3175**	**46**	**84**	**14**	**428**	**40**	**401**	**27**
- Finland	1197	43	1166	46	31	14	268	41	254	14
- Sweden	2063	43	2009	46	53	14	159	39	147	12
Central maritime	**23152**	**42**	**22860**	**44**	**292**	**8**	**26052**	**42**	**25808**	**244**
- Belgium	1518	42	1498	44	19	8	2397	41	2356	40
- Denmark	797	42	787	44	10	8	404	43	400	4
- Ireland	594	42	586	44	7	8	829	42	818	11
- Luxemburg	69	42	68	44	1	8	102	40	99	2
- Netherlands	2411	42	2381	44	30	8	3279	41	3222	57
- United Kingdom	8862	42	8750	44	112	8	11462	42	11358	104
- France	8901	42	8789	44	112	8	7580	43	7554	26
Central continental	**17467**	**37**	**17124**	**37**	**343**	**15**	**21291**	**37**	**20754**	**537**
- Austria	1579	37	1548	37	31	15	1116	37	1087	29
- Germany	15888	37	15576	37	312	15	20175	37	19667	508
South	**8214**	**26**	**2706**	**17**	**5508**	**36**	**7622**	**26**	**2529**	**5093**
- Cyprus	54	26	18	17	36	36	82	33	6	76
- Greece	725	26	239	17	486	36	546	28	150	396
- Italy	3946	26	1300	17	2646	36	4929	27	1545	3384
- Malta	27	26	9	17	18	36	60	33	5	55
- Portugal	720	26	237	17	483	36	265	22	153	112
- Spain	2742	26	903	17	1838	36	1739	25	670	1069
Baltics	**1695**	**45**	**1680**	**47**	**15**	**11**	**687**	**44**	**674**	**13**
- Lithuania	832	45	824	47	8	11	314	44	309	4
- Latvia	547	45	542	47	5	11	267	45	263	3
- Estonia	316	45	313	47	3	11	106	40	101	5
Central	**9076**	**40**	**8881**	**42**	**195**	**14**	**9250**	**40**	**9055**	**195**
- Poland	4953	40	4847	42	106	14	5045	40	4921	124
- Czech rep	1323	40	1295	42	28	14	1190	40	1164	26
- Hungary	1312	40	1283	42	28	14	1573	40	1550	23
- Slovakia	695	40	680	42	15	14	754	41	746	9
- Slovenia	259	40	253	42	6	14	153	40	150	3
- Croatia	534	40	523	42	11	14	536	40	525	11
Romania and Bulgaria	**4346**	**35**	**4128**	**35**	**218**	**29**	**3183**	**35**	**3069**	**114**
- Rumania	3280	35	3115	35	165	29	2946	35	2869	77
- Bulgaria	1066	35	1013	35	54	29	237	34	200	37
EU28	**67210**	**37**	**60554**	**39**	**6656**	**28**	**68512**	**37**	**62290**	**6222**

4 Conclusions

This study quantifies the impact of the application of high-performance glazing in existing and future buildings on energy savings and CO_2 reduction for five scenarios of penetration of high-performance glazing.
The calculation method used corresponds to the EPBD standard developed for the determination of heating and cooling loads of buildings. Information on building stock, material properties and meteorological data comes from European studies and statistics.

Sets of two calculations are used to determine the potential energy savings:

– in the first calculation, the annual heating and cooling energy is calculated for the building with reference glazing, which is already present in existing buildings or is expected to be applied in future buildings;
– in the second calculation, the annual heating and cooling energy is calculated for the same building with high performance glazing. The properties for high performance glazing are provided by Glass for Europe for the different buildings, regions, building periods and horizons.

Subtraction of the annual energy requirements resulting from the two calculations reveals the potential annual energy savings for heating and cooling. Subsequently, potential CO_2 reductions are derived from the annual energy savings and the assumed country and period specific carbon intensities.

The potential annual energy savings and CO_2 reductions are calculated for five scenarios of penetration of high-performance glazing:

Scenario 1: application of high performance glazing in 1% of the buildings in 2020;

Scenario 2: application of high performance glazing in 1% of the buildings in 2030;
Scenario 3: application of high performance glazing in 10% of the buildings between 2020 and 2030, simulating the impacts of a 1% window renovation rate over 10 years;

Scenario 4: application of high performance glazing in all buildings in 2030;

Scenario 5: application of high performance glazing in all buildings in 2050.

Scenarios 1, 2 and 3 focus on renovation of existing buildings. Scenarios 4 and 5 comprises the savings induced by high-performance glazing being installed on both renovation buildings and new buildings.

For all scenario's, boundary conditions as for instance system efficiencies, air conditioning integration rates, demolition rates and carbon intensities are taken into account for the specified periods.

It should be noted that this study focuses on the impact of improved windows only. Renovation of buildings often includes a combination of renovation measure which, while further increasing the total savings, dilutes shares of savings attributable to a single component; e.g. windows.
The thermal properties of present and future windows are provided by Glass for Europe.

Table 18 Energy savings for heating and cooling and CO_2 reduction summarized for the EU28 Member States

Scenario	**Building stock fraction**	**Horizon**	**Annual energy savings total**		**Annual energy savings for heating**		**Annual energy savings for cooling**		**Annual CO_2 reduction**	
	[%]	**[year]**	**[kToe]**	**[%]**	**[kToe]**	**[%]**	**[kToe]**	**[%]**	**[kTon]**	**[%]**
1	1%	2020	902	0,37	858	0.39	44	0,14	1171	0,33
2	1%	2030	1272	0,49	1203	0.53	69	0,20	1572	0,46
3	10%	2030	9065	3,5	8578	3.84	487	1,5	11473	3,3
4	100%	2030	75514	29	70028	31.1	5486	16	94230	28
5	100%	2050	67210	37	60554	38.9	6656	28	68512	37

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6 Signature

Delft, April 10, 2019

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Appendix A

Annex to the TNO report on Potential impact of advanced glazing on energy and CO_2 savings in Europe (2019)

Author: Glass for Europe

Contents

1. Definition of U_w and g_w values for the current building stock over ages

For the calculations, today's building stocks - composed of residential and non-residential buildings - have been defined based on five periods; i.e. before 1975 and periods 1975-1990, 1991-2002, 2002-2006 and 2007-2020.

The windows' performances per country cluster for each of these building ages have been defined based on the study commissioned by the European Commission **LOT32** "Ecodesign of Window Products" to ift Rosenheim, VHK and VITO (2015).

The **LOT32** study provides the market share of 11 windows type (ranging from single glazing to triple IGU solar control with Low-e coating and argon filling, thermally improved spacer and improved frame) per decade (from 1910 to 2010) and per EU member state.

The market share for the relevant decades was extracted from this source providing percentages per window type for each of the five periods covered in the present report. The 11 windows types were then grouped in four "insulating glass units' (IGU) families" (i.e. single glazing, double glazing unit, double glazing unit coated and triple glazing unit) to work on the basis of glazing values.

For each of the IGU families typical glazing values (i.e. U_g and g_g) were defined by Glass for Europe's members as follows:

Glazing family	U_g	g_g
SGU	5.8	0.87
DGU	2.9	0.77
DGU coated	1.3	0.62
TGU	0.7	0.5

Table 1: glazing families for the definition of glazing values in the EU Member States per building age

On the basis of the estimated sales provided in the LOT32 a typical glazing value for the relevant decades (i.e. from 1960 to 2010) was identified for each country weighting the glazing values defined by Glass for Europe's members using two formulas:

Average U_g value [decade X] = y_1% of "SGU" x U_g value + y_2% x "DGU" U_g value + y_3% x "DGU coated" U_g value + y_4% x "TGU" U_g value + y_5% x "DGU coated" U_g value

Average gg value [decade X] = z_1% x "SGU" g_g value + z_2% x "DGU" g_g value + z_3% x "DGU coated" g_g value + z_4% x "TGU" g_g value + z_5% x "TGU" g_g value

To **integrate the glazing values** (i.e. U_g and g_g) in **window values** (i.e. U_w and g_w) for the calculation of building' savings the formula below was used:

$$U_W = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \qquad (1)$$

where

U_g is the thermal transmittance of the glazing, W/(m^2 K)

U_f is the thermal transmittance of the frame, W/(m^{2}K)

Ψ_g is the linear thermal transmittance for the glazing, W/(m K)

A_g is the area of the glazing, m^2

A_f is the area of the frame, m^2

l_g is the perimeter length of the glazing, m.

In addition to the U_g and g_g values defined per country cluster age, the following parameters were computed (regardless of the building age until 2020):

Frame fraction: 0.2

Perimeter: 2.5m

U-Frame: 2.25

Psi: 0.06

The final outcome was then analysed and confirmed by Glass for Europe's expert companies as a fair estimate of the windows installed in the different buildings over the different periods per country cluster.

2. Definition of U_w and g_w values for the periods 2020-2030 and 2030-2050

To quantify the potential impact of the application of high-performance glazing on annual energy savings and CO_2 reductions for EU28 for five scenarios, high performance glazing properties had to be defined by Glass for Europe's members for the two periods: 2020-2030 and 2030-2050.

The performance of the "high performance glazing" products differ between the first and the second periods for the scenario. In the first period, the windows installed is based on a mix of high-performance glazing products already available today on the EU market. By contrast, the windows installed in the second period (2030-2050) are not yet available products and are based on a fair estimate of the potential evolution of the glazing performance over the next decades.

For the purpose of this study, it was decided not to include products such as evolutive windows (which can change its light transmission properties depending on the solar irradiance) or glazing integrated photovoltaics (which can generate solar energy). This decision was made due to limits to the calculation model and does not reflect any assessment of the future uptake of these products in the coming decades. It must be noted that these products are already marketed and it cannot be ruled out that their uptake in the next decades will further increase the savings presented in the present report.

A. First period: 2020-2030

The high-performance glazing for the first period (2020-2030) are based on existing products, already available on the market, which are considered by Glass for Europe's members effective to reduce the energy consumption and related emissions in the different building types per country clusters.

To define the values to be computed the following methodology was applied:

1°) Definition of seven glazing types available on the market today and set their respective U_g and g_g values

2°) Distinction between the glass products installed in the residential and non-residential segments

3°) Distinction between the glass products installed in new buildings or for renovation in the residential segment

4°) Selection of the most performing glass products for the residential segment (solar control, low-e or combination) depending on the building location and taking into account the facades' orientations

5°) Final processing of glazing values in the different clusters of countries depending on the building type

6°) Integration of the glazing values in window values

1. Definition of 7 glazing types

In total, **seven glazing types** were defined by Glass for Europe's members with different U_g and g_g values, providing a **realistic range of energy efficient glazing solutions** for window replacement or equipping new buildings.

Glazing #	Glazing type	U_g	g_g
1	Double	1.1	0.62
2	Double+	1	0.5
3	Double SC	1.1	0.4
4	Double SC+	1	0.3
5	Triple	0.6	0.5
6	Triple+	0.5	0.5
7	Triple SC	0.6	0.25

TABLE 2: Glazing types for 2020-2030

2. Distinction between the glass products installed in the residential and non-residential segments

The residential and non-residential buildings differ substantially on two main characteristics:

1°) The glass to façade share: with larger glazing areas in the non-residential buildings, e.g. 25% in dwelling compared to 80% in non-residential buildings;

2°) The market penetration of air conditioning equipment: with larger uptake in the non-residential buildings compared to the residential buildings. It is estimated that 60% of non-residential buildings are currently equipped with cooling systems compared to 15% of the residential buildings in Europe, source IEA "The Future of Cooling" (2018).

These two fundamental differences are well known of architects and buildings professional which explain that **solar control glazing solutions became the norm in non-residential building segment** over the last decade (being for window replacement or new buildings). This is reflected in the 2020-2030 scenario which foresees all future windows in the non-residential segment will be equipped with solar control glazing.

3. Distinction between the glass products installed in new buildings or for renovation in the residential segment

The Energy Performance of Buildings Directive main objective is that the EU building stock in 2050 is decarbonized. To achieve this objective the Directive (as revised in 2018) foresees that all new buildings constructed as of 2020 must be "nearly zero energy". For existing buildings, the directive set the obligation for member states to define minimum performance requirements for the building elements which are retrofitted or replaced. The distinction between the two segments (i.e. renovation and new buildings) led to a different uptake of the most energy performant products. In practice, more performing products are installed in new buildings, while their uptake is more limited for renovation due to lowest requirements set in the legislation and the conditions applying to these (see Ecofys (2017)).

In view of the above, to be closer to the market reality and in view of the absence of modifications on these elements brought by the last reform of the EPBD, the **uptake of best available glazing solutions is higher in the new residential buildings' segment compared to the renovation**.

While the above is true for the residential building segment, experts consider the gap in energy performance of the glazing installed for renovation or new construction in the non-residential sector is less significant. This difference is often explained by the role played by architects in the decisions related to the renovation of non-residential buildings, by contrast with the residential segment for limited renovation. Therefore, Glass for Europe's members decided **not to make a distinction between the products installed for renovation and new buildings in the non-residential segment**.

4. Selection of the most performing glass products for the residential segment (solar control, low-e or combination) depending on the building location and taking into account the facades' orientations

a. Selection of the most performing glass products (solar control or low-e)

In view of the climatic conditions and in particular solar irradiance and exposure in the **South and Bulgaria & Romania clusters**, **only solar control glazing is used** on all façades of the residential buildings to avoid over-heat and use of cooling.

By contrast, **in the North, Central maritime, Central continental, Baltics and Central clusters** the climatic conditions do not require to equip the buildings with solar control glass on all the facades of the residential buildings. Nevertheless, it is well known from building's professionals that solar control glass is the optimal energy efficiency option for the façade facing South (i.e. to avoid over-heat and use of cooling in the months with highest solar exposure). Therefore, it was decided that **a combination of solutions with low-e equipping three of the four residential building's façades and solar control glazing equipping the façade facing South has to be integrated in the calculation model** (see 4.b).

b. Selection of the most performing glass products combination taking into account the façades' orientations

The calculation tool developed by TNO for the update of the present report does not allow to make a distinction between the orientations of the façades of the building. For each building type per country cluster only one set of values (U_w and g_w) can be applied and not one per building's orientation.

To overcome this shortcoming in the calculation model, Glass for Europe's members decided to create a single set of values (U_w and g_w) combining 4 products (one for each of the building's façade) in the North, Central maritime, Central continental, Baltics and Central clusters.

Since no scientific article could be found, while doing the review of the literature, on variations in the glass to façade share depending on the orientations of the building's façades, it was decided that the share should be the same for each orientation. On this basis, when creating an artificial single set of values (U_w and g_w) for the residential buildings in the North, Central maritime, Central continental, Baltics and Central clusters, the average mean was used using four U_w and g_w values (one for each façade).

5. Final processing of glazing values in the different clusters of countries depending on the building type

Glass for Europe's members consider that scenarios where all windows are equipped with the chosen highly efficient glazing is not realistic. To remain plausible correction factors were applied to the uptake of these to take into consideration extra factors such as the temporality (i.e. lower uptake in the first years of the period), technical building's considerations, and climatic differences in countries (which could not be taken into consideration by a model based on countries' borders).

To maintain a conservative approach to the work and avoid artificially high savings, correction factors were introduced to limit the uptake of the highly efficient glazing to between 70 and 90% depending on clusters of countries and buildings' segments (new/renovation, residential/non-residential).

The table below gives the outcome of the calculation of the glazing values for the residential (renovation and new) and non-residential sector per country cluster and orientations.

	Residential renovation				Residential new				Non Residential renovation and new			
Country cluster	$U_{g\ N\text{-}E\text{-}W}$	$g_{g\ N\text{-}E\text{-}W}$	$U_{g\ South}$	$g_{g\ South}$	$U_{g\ N\text{-}E\text{-}W}$	$g_{g\ N\text{-}E\text{-}W}$	$U_{g\ South}$	$g_{g\ South}$	U_g	g_g	$U_{g\ South}$	$g_{g\ South}$
North	0.52	0.5	0.72	0.265	0.51	0.5	0.68	0.26	0.64	0.255	NA (SC all orientations)	
Central maritime	0.69	0.5	0.98	0.315	0.63	0.5	0.97	0.305	0.965	0.3		
Central continental	0.61	0.5	0.72	0.265	0.52	0.5	0.68	0.26	0.665	0.2625		
South	1.07	0.37	1.07	0.37	1.02	0.32	1.02	0.32	1.015	0.315		
Baltics	0.57	0.5	0.72	0.265	0.52	0.5	0.68	0.26	0.66	0.2575		
Central	0.67	0.5	0.72	0.265	0.63	0.5	0.68	0.26	0.665	0.2625		
Bulgaria & Romania	1.07	0.37	1.07	0.37	1.02	0.32	1.02	0.32	1.015	0.315		

TABLE 3: glazing values per country cluster / segment and orientation(s) for 2020-2030

To group these values in one single value, taking into account the building orientations, the following formulas have been used for each of the residential categories (i.e. renovation and new):

Single glazing values:

*U_g single value = U_g N-E-W * 0.75 + U_g South *0.25*

*g_g single value = g_g N-E-W * 0.75 + g_g South *0.25*

The final single glazing values for 2020-2030 are listed in the table below.

	Residential renovation		Residential new		Non Residential (renovation and new)	
Country cluster	Average U_g	Average g_g	Average U_g	Average g_g	Average U_g	Average g_g
North	0.57	0.44	0.55	0.44	0.64	0.26
Central maritime	0.76	0.45	0.72	0.45	0.97	0.30
Central continental	0.64	0.44	0.56	0.44	0.67	0.26
South	1.07	0.37	1.02	0.32	1.02	0.32
Baltics	0.61	0.44	0.56	0.44	0.66	0.26
Central	0.68	0.44	0.64	0.44	0.67	0.26
Bulgaria & Romania	1.07	0.37	1.02	0.32	1.02	0.32

TABLE 4: final single glazing values for 2020-2030

6. Integration of the glazing values in window values

The final step in the calculation model is to convert the Average U_g and g_g values in U_w and g_w values to compute them in the calculation tool by TNO.

To **integrate the glazing values** (i.e. U_g and g_g) in **window values** (i.e. U_w and g_w) for the calculation of building' savings the formula below was used:

$$U_W = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \qquad (1)$$

where

U_g is the thermal transmittance of the glazing, W/(m^2 K)

U_f is the thermal transmittance of the frame, W/(m^{2}K)

Ψ_g is the linear thermal transmittance for the glazing, W/(m K)

A_g is the area of the glazing, m^2

A_f is the area of the frame, m^2

l_g is the perimeter length of the glazing, m.

In addition to the U_g and g_g values defined per country cluster age, the following parameters were computed:

Frame fraction: 0.2

Perimeter: 2.5m

U-Frame: 1.6

Psi: 0.06

The final single values used in the TNO calculation tool for 2020-2030 are listed in the table below.

REPLACED 2020-2030	Residential renovation		Residential new		Non Residential renovation + new	
	U_w	g_w	U_w	g_w	U_w	g_w
North	0,93	0,32	0,91	0,32	0,98	0,19
Central maritime	1,08	0,32	1,05	0,32	1,25	0,22
Central continental	0,98	0,32	0,92	0,32	1,01	0,19
South	1,33	0,27	1,29	0,23	1,29	0,23
Baltics	0,96	0,32	0,92	0,32	1	0,19
Central	1,01	0,32	0,98	0,32	1,01	0,19
Bulgaria & Romania	1,33	0,27	1,29	0,23	1,29	0,23

TABLE 5: *final window values for 2020-2030*

B. Second period: 2030-2050

The second period (2030-2050) differs substantially from the first period 2020-2030 in that it is to be expected that the products which are going to be available on the market are not yet known. Therefore, their performance had to be estimated by Glass for Europe's members.

To define the values to be computed for the period 2030-2050, the same methodology used for the first period (2020-2030) was used:

1°) Definition of four glazing types and their respective U_g and g_g values

2°) Distinction between the glass products installed in the residential and non-residential segments

3°) Distinction between the glass products installed in new buildings or for renovation in the residential segment

4°) Selection of the most performing glass products for the residential segment (solar control, low-e or combination) depending on the building location and taking into account the facades' orientations

5°) Final processing of glazing values in the different clusters of countries depending on the building type

6°) Integration of the glazing values in window values

1. Definition of 4 glazing types

In total, **four glazing types** were defined by Glass for Europe's members with different U_g and g_g values, providing an **estimate of the potential evolution of the glazing performance** between 2030-2050. These figures need to be taken with caution since they reflect only a conservative estimate based on today's knowledge and do not include products such as evolutive windows (which can change light transmission and solar heat gain properties depending on the solar irradiance) or glazing integrated photovoltaics (which can generate solar energy).

Glazing #	**Glazing type**	U_g	g_g
1	Low-e ++ A	0.35	0.65
2	Low-e ++ B	0.25	0.55
3	Solar control ++ A	0.4	0.3
4	Solar control ++ B	0.5	0.2

TABLE 6: Glazing types for 2030-2050

2. Distinction between the glass products installed in the residential and non-residential segments

As underlined in the previous section on the first period 2020-2030, the residential and non-residential buildings differ substantially on the glass to façade share and the market penetration of air conditioning equipment.

For the second period, it was assumed that the glass to façade share will not change, although it is not unreasonable to consider this could increase (in particular in the residential sector) with more attention payed to the multiple benefits of benefits for the occupants (see report by David Strong Consulting, "The distinctive benefits of glazing: *The social and economic contributions of glazed areas to sustainability in the built environment*" 2012).

By contrast, according on the IEA report “The Future of Cooling” (2018). The cooling system integration rates are expected to substantially increase from 15% average in the residential segment today to 50% in 2050, and from 60% to 85% in the non-residential segment. One could expect this will create an increased demand for solar control glazing solutions to mitigate the need to use air-conditioning systems and its related costs.

For the 2030-2050 period, it was decided to apply the same pattern as the one described for the 2020-2030 period with **solar control glazing solutions being the norm only in the non-residential building segment**. This said, it cannot be ruled out that the glass to façade share will change in the future and that solar control glazing will follow the same pattern in the residential segment.

3. Distinction between the glass products installed in new buildings or for renovation in the residential segment

By contrast with the 2020-2030 age, Glass for Europe’s members decided not to distinguish glass products installed in new buildings or for renovation in the residential segment. For the 2030-2050 period, it is impossible to estimate if a distinction between new buildings and renovation will still exist. It is due to the many uncertainties regarding the legislation which will be in place and future requirements for new buildings and for the renovation of the existing building stock. **Therefore, the same products are used for new buildings and for renovation in the residential segment.**

4. Selection of the most performing glass products for the residential segment (solar control, low-e or combination) depending on the building location and taking into account the facades’ orientations

a. Selection of the most performing glass products (solar control or low-e)

In view of the climatic conditions and in particular solar irradiance and exposure in the **South and Bulgaria & Romania clusters**, **only solar control glazing is used** on all façades of the residential buildings to avoid over-heat and use of cooling.

By contrast, **in the North, Central maritime, Central continental, Baltics and Central clusters** the climatic conditions do not require to equip the buildings with solar control glass on all the facades of the residential buildings. Nevertheless, it is well known from building’s professionals that solar control glass is the optimal energy efficiency option for the façade facing South (i.e. to avoid over-heat and use of cooling in the months with highest solar exposure). Therefore, it was decided that **a combination of solutions with low-e equipping three of the four residential building’s façades and solar control glazing equipping the façade facing South has to be integrated in the calculation model** (see 4.b).

b. Selection of the most performing glass products combination taking into account the façades’ orientations

The calculation tool developed by TNO for the update of the present report does not allow to make a distinction between the orientations of the façades of the building. For each building type per country cluster only one set of values (U_w and g_w) can be applied and not one per building’s orientation.

To overcome this shortcoming in the calculation model, Glass for Europe’s members decided to create a single set of values (U_w and g_w) combining 4 products (one for each of the building’s façade) in the North, Central maritime, Central continental, Baltics and Central clusters.

Since no scientific article could be found, while doing the review of the literature, on variations in the glass to façade share depending on the orientations of the building’s façades, it was decided that the share should be the same for each orientation. On this basis, when creating an artificial single set of values (U_w and g_w) for the residential buildings in the North, Central maritime, Central continental, Baltics and Central clusters, the average mean was used using four U_w and g_w values (one for each façade).

5. Final processing of glazing values in the different clusters of countries depending on the building type

The table below gives the outcome of the calculation of the glazing values for the residential (renovation and new) and non-residential sector per country cluster and orientations.

	Residential renovation				Residential new				Non Residential renovation and new			
Country cluster	$U_{g\ N\text{-}E\text{-}W}$	$g_{g\ N\text{-}E\text{-}W}$	$U_{g\ South}$	$g_{g\ South}$	$U_{g\ N\text{-}E\text{-}W}$	$g_{g\ N\text{-}E\text{-}W}$	$U_{g\ South}$	$g_{g\ South}$	U_g	g_g	$U_{g\ South}$	$g_{g\ South}$
North	0.25	0.55	0.4	0.3	0.25	0.55	0.4	0.3	0.4	0.3	NA (SC all orientations)	
Central maritime	0.35	0.65	0.4	0.3	0.35	0.65	0.4	0.3	0.4	0.3		
Central continental	0.25	0.55	0.4	0.3	0.25	0.55	0.4	0.3	0.4	0.3		
South	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2		
Baltics	0.25	0.55	0.4	0.3	0.25	0.55	0.4	0.3	0.4	0.3		
Central	0.35	0.65	0.5	0.2	0.35	0.65	0.5	0.2	0.5	0.2		
Bulgaria & Romania	0.4	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.5	0.2		

TABLE 7: glazing values per country cluster / segment and orientation(s) for 2030-2050

As for the 2020-2030 scenario, these values are grouped in one single value, taking into account the building orientations, with the following formulas for the residential categories (i.e. renovation and new):

Single glazing values:

U_g *single value =* U_g *N-E-W * 0.75 +* U_g *South *0.25*

g_g *single value =* g_g *N-E-W * 0.75 +* g_g *South *0.25*

The final single glazing values for 2030-2050 are listed in the table below.

	Residential renovation		Residential new		Non Residential (renovation and new)	
Country cluster	Average U_g	Average g_g	Average U_g	Average g_g	Average U_g	Average g_g
North	0.29	0.49	0.29	0.49	0.40	0.30
Central maritime	0.36	0.56	0.36	0.56	0.40	0.30
Central continental	0.29	0.49	0.29	0.49	0.40	0.30
South	0.50	0.20	0.50	0.20	0.50	0.20
Baltics	0.29	0.49	0.29	0.49	0.40	0.30
Central	0.39	0.54	0.39	0.54	0.50	0.20
Bulgaria & Romania	0.40	0.30	0.40	0.30	0.50	0.20

TABLE 8: final single glazing values for 2030-2050

6. Integration of the glazing values in window values

The final step in the calculation model is to convert the Average U_g and g_g values in U_w and g_w values to compute them in the calculation tool by TNO.

To **integrate the glazing values** (i.e. U_g and g_g) in **window values** (i.e. U_w and g_w) for the calculation of building' savings the formula below was used:

$$U_W = \frac{A_g U_g + A_f U_f + l_g \psi_g}{A_g + A_f} \qquad (1)$$

where

U_g is the thermal transmittance of the glazing, W/(m^2 K)

U_f is the thermal transmittance of the frame, W/(m^{2}K)

Ψ_g is the linear thermal transmittance for the glazing, W/(m K)

A_g is the area of the glazing, m^2

A_f is the area of the frame, m^2

l_g is the perimeter length of the glazing, m.

In addition to the U_g and g_g values defined per country cluster age, the following parameters were computed:

Frame fraction: 0.2

Perimeter: 2.5m

U-Frame: 1.6

Psi: 0.03

The final single values used in the TNO calculation tool for 2030-2050 are listed in the table below.

REPLACED 2030-2050	Residential renovation + new		Non Residential renovation + new	
	U_w	g_w	U_w	g_w
North	0,63	0,35	0,72	0,22
Central maritime	0,68	0,4	0,72	0,22
Central continental	0,63	0,35	0,72	0,22
South	0,8	0,14	0,8	0,14
Baltics	0,63	0,35	0,72	0,22
Central	0,71	0,39	0,8	0,14
Bulgaria & Romania	0,72	0,22	0,8	0,14

TABLE 9: *final window values for 2030-2050*