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Integration of energy smart materials in non-residential buildings

Switch2Save

Lightweight switchable smart solutions for energy saving large windows and glass facades

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= Deliverable D1.1 =

Specification sheets for energy smart IGUs

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Executive Summary

Switch2Save targets the development of switchable, active, transparent energy smart materials capable of controlling the energy transfer through glass-based building envelopes. For this purpose, Switch2Save focuses on electrochromic (EC) or thermo-chromic (TC) glazing systems for non-residential buildings that will be combined to form Integrated Glass Units (IGU). Their intelligent switching will allow significant reduction of heating and cooling energy demand in winter and summer, respectively, as well as energy demand for lighting.

In this deliverable the thermal, comfort and lighting specifications for the new systems (IGU) as well as the relevant requirements for the demonstration buildings are defined. D1.1 sets the basis for the project developments foreseen as part of the DoA, by reviewing existing requirements for glazing systems and correlating their characteristics to building typologies, climatic requirements and the energy saving and lighting regulatory framework.

After a short introduction, the second section of D1.1 presents an extensive review of the literature related to glazing systems, their integration in building envelopes and the interaction with it (regarding thermal, visual but also safety aspects). In paragraphs 2.1 and 2.2, typologies of non-residential high WWR (Window to Wall Ratio) building in Europe and climatic data of the target countries (Belgium, Germany, Greece and Sweden) are presented respectively. Almost half of the building stock has been built before 1970 with WWR approximately 30%, whereas in newer offices the WWR doubles to 60%. The U-value of external walls and windows ranges from 1.61 and 4.18 to 0.18 and 0.90 respectively for the target countries. The climate of the target countries ranges from Mediterranean in South Europe to Cold Continental in North Europe.

Then in paragraph 2.3, thermal comfort requirements and standards are presented and analysed. The fundamental standards regarding the comfort conditions are EN 15251, ASHRAE 55, ISO 7730 and ASHRAE 62.1. These standards define the basic measures for thermal comfort assessment which are the Predicted Mean Vote (PMV), the Predicted Percentage Dissatisfied (PPD), the discomfort due to draught and vertical air temperature difference, the floor surface temperature and the radiant temperature asymmetry.

An overview of the requirements of non-residential buildings regarding daylight and interior lighting follows in Section 2.4. The so called *Human Centric Lighting* (HCL) is presented as an approach comprising Visual light effect, Emotional light effect and Biological light effect. The requirements for indoor lighting are then presented based on the European standard EN 12464. According to the standard these are related to luminance distribution, cylindrical illuminance, illuminance calculation, verification grids, glare restriction, flicker restriction, colour of light and colour reproductivity (colour rendering). The role of daylight harvesting is discussed in relation to EN 15193 as well as the daylight factor and the lighting management and lighting control.

Section 2.5 summarizes the energy saving standards for the target countries. The national standards of the four countries are described emphasizing on the regulations regarding the non-residential buildings. Each country has different strategy in order to improve the energy efficiency of buildings and to increase the number of nZEB fulfilling the European Directives (EPBD). However, the upgrade of building envelope and, in consequence, the glazing systems is a common strategy of national regulations, especially for the non-residential buildings.

Section 2.6 and 2.7 describe the basic specifications and requirements of glazing systems. The most important specifications, such as the U-value, the g-value, the window frame, the optical characteristics and the air permeability are defined. Moreover, the glazing requirements related to the reaction and the resistance to fire are presented, according to international standards. Finally, the international standards regarding the glazing systems are summarized and more emphasized is given in standards for adaptive glazing systems (paragraph 2.8). So far, no European standard or regulation concerning specifically adaptive glazing has been published. The only regulation that refers specifically to adaptive glazing is the international standard ISO 18543.

In the third section, the requirements for the three demonstrators (the NTUA mock-up and the Nikaia Hospital in Greece and the Vasakronan office building in Sweden) are defined. Specifically, the thermal, acoustic and visual comfort requirements of the buildings (hospital and office) are defined based on their operation and the national regulations. This section is linked with Appendix A which presents the Specification Sheets of the demonstrators giving information about the dimensions and the design of the glazing systems.

Nomenclature

Abbreviation	Explanation
ACH	Air Change per Hour
CDD	Cooling Degree Days
D	Daylight factor
DR	Draught Rate
EC	Electrochromic
EP	Primary energy number
EPB	Energy Performance of buildings
HCL	Human Centric Lighting
HDD	Heating Degree Days
PD	Percentage of Dissatisfied
PEC	Primary Energy Consumption
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
R_a	Colour Rendering Index
TC	Thermochromic
U_g, U_f and U_w	Thermal transmittance of the glass, frame and window
WWR	Window to Wall Ratio
Ψ	Linear thermal transmittance

Table of Contents

1. Introduction

Deliverable D1.1 "*Specification sheets for energy smart IGUs*" has been prepared in the frame of Task 1.1 "*Identification of building design related requirements; regulatory boundary conditions and specification sheets* (M1-M6). The aim of the D1.1 is to identify building design related requirements, regulatory boundary conditions and specifications for office buildings in the target countries and specifically for the two demo buildings of the project (hospital wards and office building). Selected target countries are Belgium, Germany, Greece and Sweden, covering a wide range of climate conditions in Europe. Deliverable D1.2 "Specifications for virtual demonstration cases" accompanies D1.1 and sets the same requirements for the two demonstration cases to be simulated (virtual demonstration) as part of the Switch2Save project.

The main objectives are:

- to provide specification sheets for EC and TC cell, IGU component and window/façade design and manufacturing,
- to review relevant standards and EU regulatory requirements for adaptive glazing,
- to define the architectural requirements for the retrofitting of the two demonstrators in Sweden and Greece and
- to provide a list of representative glass facade buildings accompanied by their drawings/technical details that could be used of technology validation in WP7.

The main activities reported in the deliverable include:

- Review of non-residential building typologies in EU countries
- Review of standards and EU regulatory requirements for glazing systems and review of requirements with respect to energy saving regulations, emphasizing on adaptive windows.
- Description of regulations and the requirements related to thermal and visual comfort in building
- Collection of climatic data for target countries
- Collect requirements towards building structure to fulfil weight and operational needs.
- Collect technical information such as IGU dimensions.
- Define current window specifications and new glazing installation and requirements for the 2 demonstrators.

The current deliverable sets the framework and undertakes all necessary tasks that create the prerequisites for the realization of the demonstration activities (WP7) and support the widespread adoption of Switch2save technical innovations (WP8).

2. Literature review

2.1. Typologies of non-residential, high WWR buildings in Europe

The classification of non-residential buildings in Europe is essential in order to identify building design related requirements and to collect data that support the market uptake of the energy smart IGUs. Based on databases and survey outcomes of past and ongoing EU initiatives, the classification focused on buildings with glass facades and high WWR. It was carried out in terms of construction age, distribution, use and ownership status, and it was based on existing databases and survey outcomes of ongoing EU initiatives. Detailed classification of typologies of non-residential buildings based on architectural configuration, unit size and key geometric indicators has not been possible as such data is currently not available, and it is beyond the scope of Switch2Save project to collect new data, especially within the timeframe of Task 1.1.

The European cities are particularly characterized by their historical building stock (residential and non-residential buildings) with 40% of it being over 50 years old [1]. Figure 2.1 illustrates the construction year of the non-residential building stock for the four target countries (Belgium, Germany, Greece and Sweden) and the European Union-28 countries (including UK). As presented, more than one third of non-residential buildings in Belgium and Greece were built before World War II, while about 40% of buildings in Germany and Sweden were built before 1969. On the other hand, less than 20% of the building stock in the four countries and overall the EU are over 20 years old.

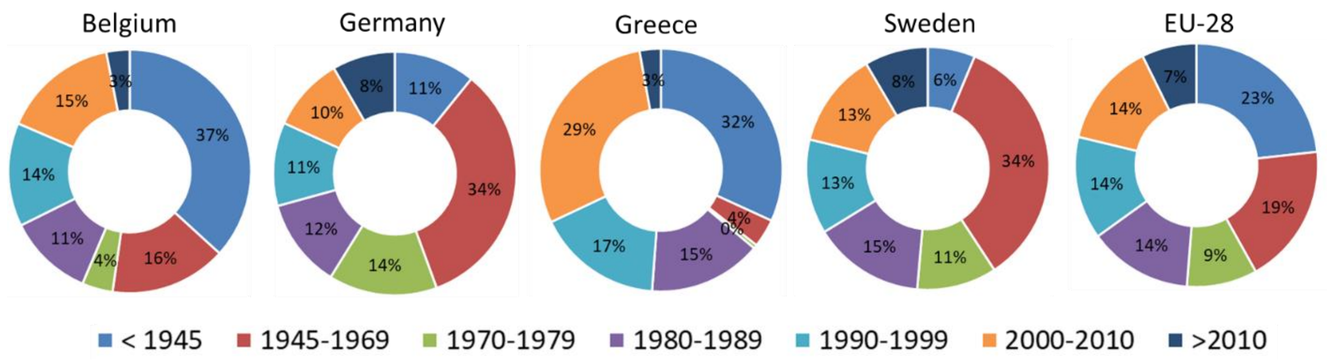

Figure 2.1 – The construction period of non-residential buildings [1].

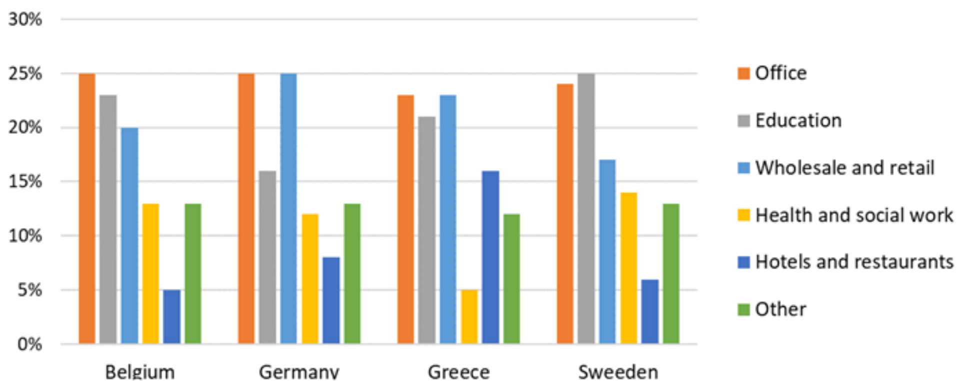

Figure 2.2 - Characteristics of non-residential building stock [1].

Figure 2.2 shows the type of non-residential buildings for the four target countries. Most of the buildings are offices, commercial (wholesale and retail) and educational buildings. In Belgium, offices account for 25%, educational buildings for 23% and commercial buildings for 20%. Healthcare buildings represent 15%, while hotels and restaurants only 5%. In Germany, offices and commercial buildings correspond to 50% of the non-residential building stock, while educational and health/social work buildings account for 16% and 12%, respectively. In Greece, the number of offices is almost equal with the commercial buildings representing the 46% of the total non-residential building stock, while the educational buildings correspond to 21%. Due to tourism, hotels and restaurants represent more than 15% of the non-residential buildings. In Sweden, educational buildings account for the 25% and offices for 24% of the building stock, while the commercial and health/social buildings represent the 17% and 14%, respectively.

Overall, office buildings hold the largest share in the non-residential building stock. Table 2.1 summarizes the office floor area for the selected four countries [2].

Table 2.1 - Country breakdown of office construction by age band [2].

Country	Total floor space (Mm^2)	Pre 1945	1945-1960	1960-1970	1970-1980	1980-1990	1990-2000	Post 2000	Unknown
Belgium	25.1	37%	14%	6%	4%	7%			
Germany	359.5	18%	7%	7%	15%	11%	19%	16%	7%
Greece	26.2	37%				18%	18%	28%	
Sweden	26.8	21%	14%	22%	22%	12%	10%		

Regarding the type of tenure, with the exception of Sweden, there is an almost equal distribution of rented and owned non-residential buildings throughout the EU (49% - 51%) (Figure 2.3). A large proportion of owner-occupied non-residential buildings are important for retrofit programs. Building owners renting out their properties are considered to be less likely to invest in upgrading works such as the replacement of glazing units, as in the short term they will not financially benefit from the resulting improvements and reduction in energy consumption (phenomenon known as “split-incentive”).

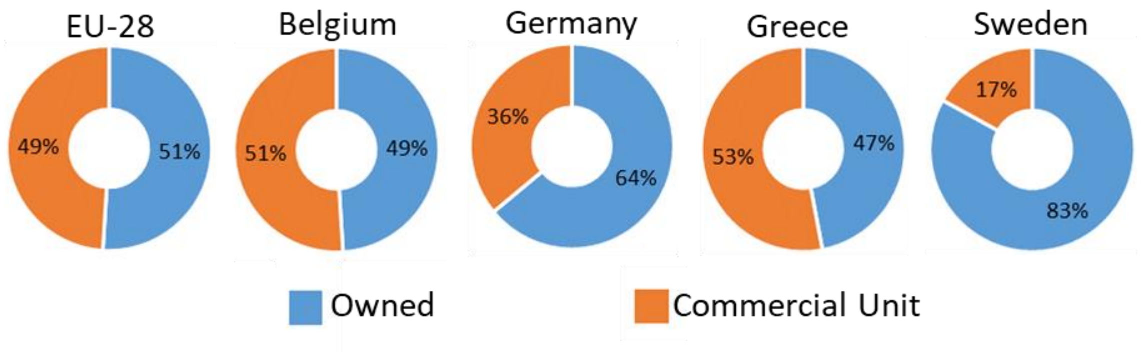

Figure 2.3 – Type of tenure of non-residential buildings [1].

The construction types across the EU, present many similarities when it comes to office buildings. Concrete structure with curtain wall facades is common in all countries. However, further categorization based on geometry, number of storeys or orientation cannot be done based on the currently available data. Literature review indicates that buildings dated before 1960 were often built from masonry brick.

A crucial aspect in the retrofitting of buildings is the façade. Facades cover large areas of a building envelope and therefore have a big effect in a building’s overall performance. An analysis of the “Emporis” database, as it was presented in iNSPiRe FP7 project [2], distinguishes the 4 prevailing façade types (Figure 2.4):

- Exposed structure (Masonry or concrete)
- Curtain wall (Glazed, aluminium panels)
- Composite façade
- Applied non load-bearing masonry

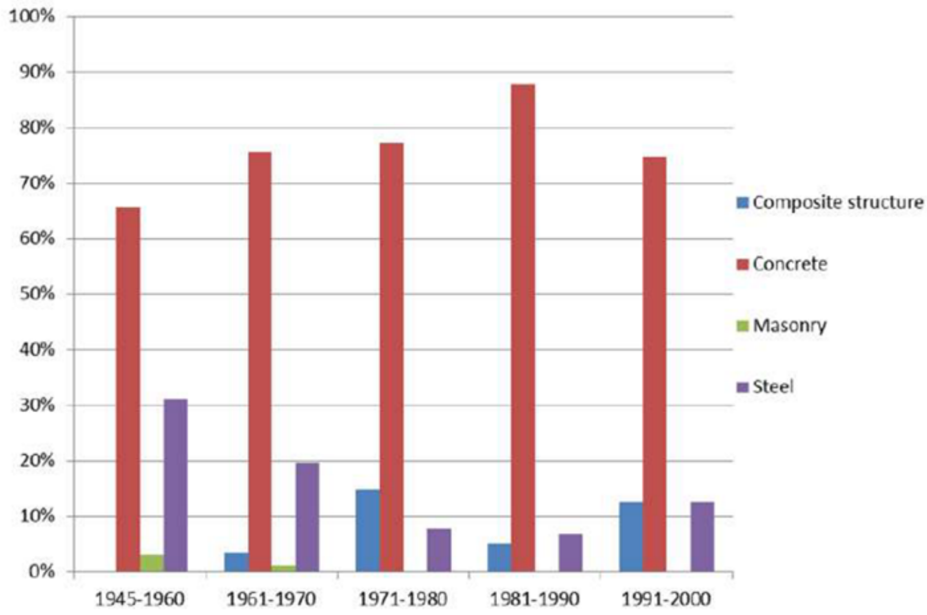

Figure 2.4 - Office buildings by structural material, analysis of Emporis database [2].

Over the years, the percentage of glazing and of non-structural infill panels in building facades has been increasing. The first curtain walls were introduced post WWII. At that time, most of the office stock had concrete structure with a brick or concrete façade. Concrete structures have been dominating the construction ever since, whereas it was in the 1970s when sandwich wall panels took over as in-fills. In the 1980s, prefabricated façade elements were introduced. It was then that glass curtain walls and/or aluminum panels started to prevail (Figure 2.5).

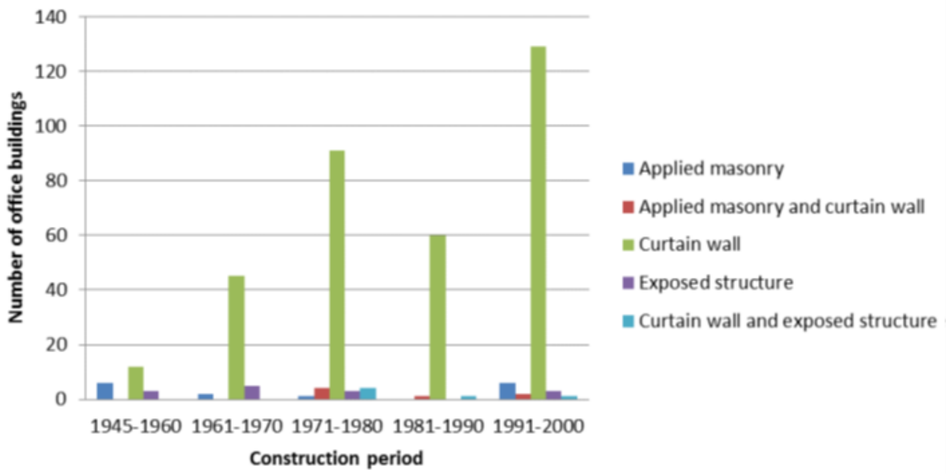

Figure 2.5 - Office buildings by façade material, analysis of Emporis database [2].

Based on conclusions derived from the iNSPiRE report that focuses on office buildings, the WWR in office buildings before 1980 is approximately 30% whereas in offices that were constructed later the WWR doubles to 60% [2].

The building sector is responsible for the largest amount of the global energy consumption, as it consumes more than one third of the global energy. In the European Union, the building sector accounts for 39% of the total energy consumption and it is responsible for 36% of the total CO_2 emissions [3, 4]. Specifically, the non-residential buildings account for the 14% of total energy consumption in EU [3]. As depicted in Figure 2.6, non-residential buildings consume energy for space heating/cooling, water heating, lighting, cooking, electrical devices etc. Among them, by far the largest amount of energy (approximately two third) is consumed for space heating, while the lighting is responsible for about 20%, consuming 35 kWhr/m^2 for the EU countries. There was no available data for Belgium and Greece.

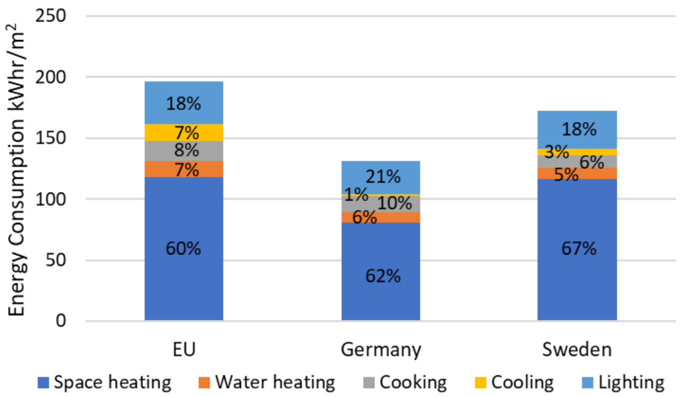

Figure 2.6 – Final energy consumption of non-residential buildings per area [1].

When it comes to energy consumption in non-residential buildings, once again the available information regarding office buildings is more detailed. We know that not all offices have AC systems, and even then, cooling is not available in all floor area. The total office floor in the EU is approximately 1.251 billion m^2. Of this, 0.987 billion m^2 is estimated to be heated [2].

Table 2.2 - Summary of floor areas per country [2].

Country	Total office (Mm^2)	Heated office	Cooled office
Belgium	25.1	22.6	16.0
Germany	359.5	323.6	229.7
Greece	26.2	23.6	23.6
Sweden	26.8	24.1	17.1

Figure 2.7 presents the final energy consumption by fuel, highlighting that nowadays the electricity is the basic energy source of non-residential buildings for all countries. Electricity is used for lighting, space cooling, electrical appliances and in several cases at space heating. In Belgium and Germany, natural gas and petroleum products account for 31-39% and 20-23%, respectively, while in Greece they contribute only by 18%. Derivated heat is used mainly in Nordic climates (Sweden). Up-to-day, renewable sources are responsible for less than 4% of the total energy consumption of non-residential buildings in all countries, while solid fuels are insignificant.

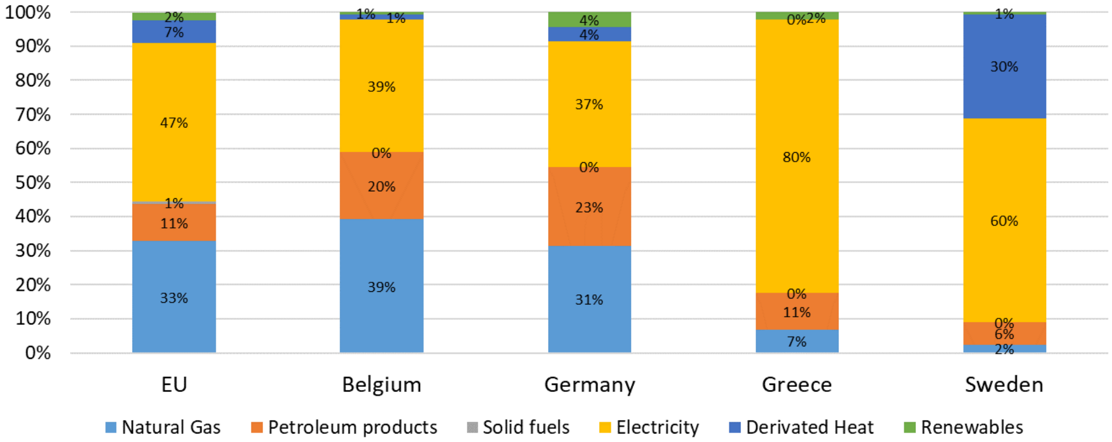

Figure 2.7 – Final energy consumption of non-residential buildings by fuel [1].

As mentioned above, the European building stock is relatively old and this reflects to the energy efficiency of the building envelopes. The thermal transmittance of the building envelope, the U-value, is an indicator of the energy performance of the building envelope. Table 2.3 presents the U-values of the external walls and windows of the non-residential buildings in terms of the construction period. The average U-value in the EU is 0.69 W/(m^{2}K) for the walls and 2.35 W/(m^{2}K) for the windows.

Table 2.3 – The U-value of external walls and windows of the non-residential buildings [1].

	U-value	Average	<1945	1945-1969	1970-1979	1980-1989	1990-1999	2000-2010	>2010
Belgium	Walls	1.38	1.90	1.80	1.75	1.70	1.30	0.48	0.40
	Windows	3.66	4.50	4.60	4.20	3.80	3.70	2.50	2.30
Germany	Walls	0.85	1.50	1.35	1.20	0.90	0.40	0.34	0.28
	Windows	1.91	2.90	2.40	2.15	1.90	1.60	1.30	1.15
Greece	Walls	1.61	2.50	2.45	2.40	2.10	0.80	0.70	0.32
	Windows	4.18	5.10	5.05	5.00	3.70	3.50	3.50	1.60
Sweden	Walls	0.30	0.60	0.40	0.30	0.25	0.20	0.19	0.18
	Windows	2.24	3.20	3.10	3.00	2.50	1.70	1.30	0.90
EU	Walls	0.69	1.35	0.95	0.78	0.66	0.49	0.33	0.27
	Windows	2.35	3.55	2.55	2.43	2.31	2.06	1.78	1.73

Over recent years, particularly after the establishment of the two European Directives: the Energy Performance of Buildings Directive (EPBD – Directive 2002/91/EU with its recast, Directive 2010/31/EU) [5, 6] and the Energy Efficiency Directive (EED – Directive 2012/27/EU) [7], the renovation rate[1] in the building sector has increased. As presented in Figure 2.8, the light-medium-deep energy related renovation rate is below 6% for all European countries, while the non-energy related renovation rate is more than 10%. The deep renovation rate which includes the upgrade of the building envelope is below 2% for all countries.

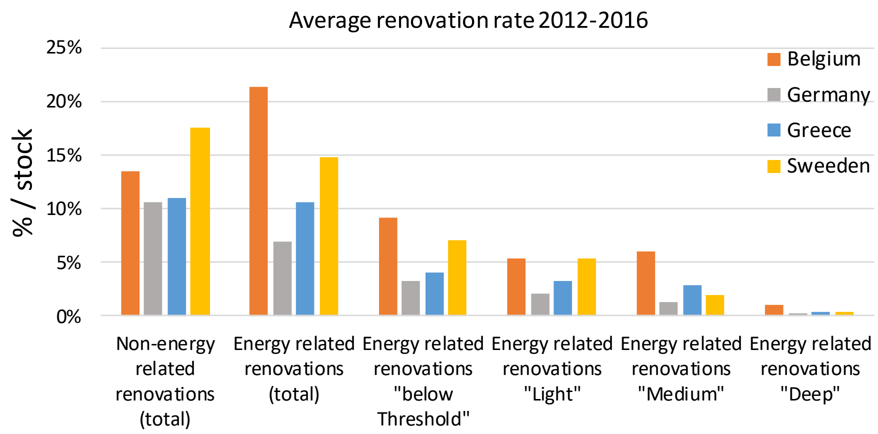

Figure 2.8 – Average renovation rate in non-residential buildings [8].

Combining the building typology data collected in this Section with the preliminary calculations already performed and presented in the Impact Section of the DoA, a rough estimation of the potential energy savings due to renovation using Switch2Save IGUS is possible. In Sweden, as Table 2.1 presents, 26.8 Mm2 of area are occupied by office buildings and ca. 25% has been built after 1980, with mean WWR 60%. Assuming an average energy-related renovation rate of ca. 15%, as Figure 2.8 suggests, one could expect 1 Mm2 of non-residential buildings built after 1980 with 60% WWR to be renovated every year. These buildings currently consume ca. 150 kWhr/m2 for HVAC and lighting (Figure 2.6). If half of these (50%) were renovated including the new Switch2Save IGUs and the energy demand reduction were 22% (as calculated in the Impact Section of the DoA), then the expected primary energy saving in Sweden could be ca. 34 GWhrs annually. In Athens, assuming the same renovation rate and the

[1] This is the cumulated affected building floor area [m^2] of all buildings that underwent an energy renovation in calendar year x (e.g. 2013) divided by the total floor area [m^2] of the building stock in the same period. The unit is [%]. The total energy renovation rate is defined as the sum of all renovation rates of the covered depths: “below threshold” (x < 3% savings), “light” (3% ≤ x ≤ 30% savings), “medium” (30% < x ≤ 60% savings) and “deep” (x > 60% savings)

same share of Switch2Save IGUs in the renovations, the respective primary energy saving would be ca. 132 GWhrs annually, as office building in Athens consume much more energy than in Sweden.

2.2. Climatic data for target countries

D1.1 presents climatic data on the basis of two classifications:

- ***INSPiRe project***: The European climate falls into 7 different categories [9]:
  - Southern Dry: Dry climate zone with extreme summer temperatures and high yearly temperature amplitudes. Summer is very warm and dry, with a seasonal relative humidity under 60%. This climate zone includes main part of Spain and Portugal, Turkey and part of Greece.
  - Mediterranean: Relatively warm climate zone with relative mild summer and winter seasons, due to the regulating influence of the Mediterranean Sea. It includes Italia and the other countries surrounding the Adriatic Sea (Croatia, Montenegro, Albania, West of Greece, Cyprus), as well as South of France and North-East of Spain.
  - Southern continental: Climate zone with summer as warm as Mediterranean summers, but with winters much colder. It includes most part of France, North Italy, Slovenia, Serbia and Bulgaria.
  - Continental: Inner land climate zone with high yearly temperature amplitudes between cold winters and hot summers. It includes Central Europe (Germany, Austria, Czech Republic, Slovakia, and Hungary) as well as parts of Ukraine, Poland and Romania.
  - Oceanic: Humid and mild climate zone with low yearly temperature amplitudes, due to the regulating influence of Atlantic Ocean. It includes the Britannic islands, Benelux, North-West of France and the extreme North-West of Spain (Galicia).
  - Northern continental: Climate zone with a mild summer and a cold winter not as extreme as the Nordic climate. It includes Countries at the South of the Baltic Sea (Denmark, Poland, and Lithuania).
  - Nordic: Climate zone with extreme winter temperatures and mild summer temperatures. It includes Scandinavian countries, North of Russia, Estonia and Latvia.

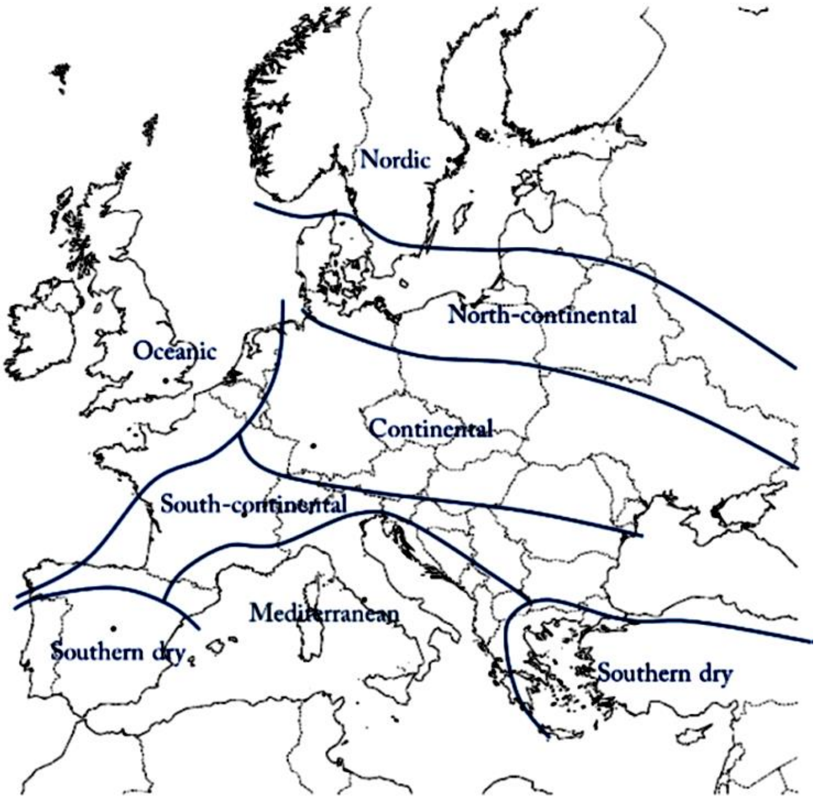

Figure 2.9 - Reference European Climates [9].

- ***Köppen Classification***:

The Köppen climate classification is one of the most widely used climate classification systems. This system was originally developed by Wladimir Köppen around 1900. Early versions were based on previous maps of vegetation growth, but it has subsequently been revised as more comprehensive monitored data became available [10]. According to Köppen – Geiger climate classification, there are four prevailing climatic zones in Europe [11].

Table 2.4 – Explanation of the four prevailing climatic zones in Europe, as illustrated in Figure 2.10.

Köppen – Geiger climate classification	Explanation
Csa -	Temperate with dry, hot summer. (Mediterranean climate)
Cfb -	Temperate without dry season and warm summer
Dfb -	Temperate continental climate/humid continental climate without dry season and with warm summer
Dfc -	Cold, without dry season and with cold summer.

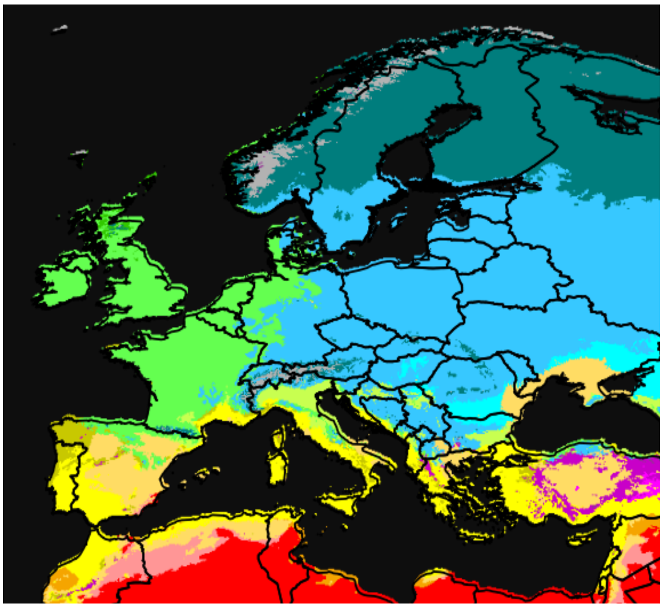

Figure 2.10 – European climates zones, according to Köppen – Geiger climate classification [10].

Switch2Save target countries belong to four different climatic categories:

- Belgium (Brussels): Oceanic climate / Cfb
- Germany (Dresden): Continental climate / Dfb
- Greece (Athens): Mediterranean climate / Csa
- Sweden (Uppsala): Nordic climate / Dfc.

An overview of the climate in these countries is given in the next sections based on the values for external temperature, relative humidity, global horizontal radiation (Gh), diffuse horizontal radiation (Dh), HDD and CDD. HDDs (Heating Degree days) and CDDs (Cooling Degree days) are weather-based technical indexes designed to describe the need for the heating and cooling energy requirements of buildings [12].

In the following paragraphs, the climate characterization of the 4 reference cities are presented.

2.2.1. Greece – Athens

Athens is in the Attica region, in the Southeast of Greece. The annual mean temperature is equal to 16.5 °C. The average winter temperatures go below 10 °C during three months of the year. The annual minimum temperature is reached in January and is equal to 0.4 °C. The summers are hot and long, with average temperatures above 20 °C from May to September and maximum temperatures up to 38 °C.

The annual relative humidity is equal to 61.3 %. Humidity percentages are higher during winter with values above 70 %. Table 2.5 shows monthly and annual value of ambient temperature, relative humidity and solar radiation in Athens.

Table 2.5 - Athens Climatic Data [13]

	T_{amb} mean [°C]	T_{amb} min [°C]	T_{amb} max [°C]	RH [%]	Gh [kWh/m²]	Dh [kWh/m²]
Jan	9.2	0.4	17.4	71.3	66.0	35.3
Feb	9.7	1.0	18.9	70.0	74.5	44.3
Mar	11.8	2.5	22.6	66.5	103.8	61.9
Apr	15.3	5.6	26.2	61.0	146.0	76.1
May	20.2	9.1	32.4	55.9	181.2	95.9
Jun	24.3	14.7	34.4	51.3	199.9	92.6
Jul	27.0	17.7	37.9	47.0	212.3	89.3
Aug	26.7	17.9	36.2	47.8	199.2	77.4
Sep	23.0	14.6	33.1	56.2	154.4	61.4
Oct	18.3	9.0	28.3	64.7	106.0	51.2
Nov	14.2	5.5	24.6	72.4	66.1	39.2
Dec	11.2	1.9	21.2	71.4	52.8	30.8
Annual	17.6	8.3	27.8	61.3	1562.1	755.4

2.2.1. Germany - Dresden

Like many places in Eastern parts of Germany, Dresden has a continental climate (Köppen climate classification Dfb), with significant continental influences due to its inland location. The summers are warm, averaging 19.0 °C) in July. The winters are slightly colder than the German average, with a January average temperature of 0.1 °C, just preventing it from being a humid continental climate (Köppen climate classification Dfb). The driest months are February, March and April, with precipitation of around 40 mm (1.6 in). The wettest months are July and August, with more than 80 mm (3.1 in) per month. Table 2.6 shows monthly and annual value of ambient temperature, relative humidity and solar radiation in Dresden.

Table 2.6 - Dresden Climatic Data [13].

	T_{amb} mean [°C]	T_{amb} min [°C]	T_{amb} max [°C]	RH [%]	Gh [kWh/m²]	Dh [kWh/m²]
Jan	-2.4	-14.0	7.2	84,2	23,8	16,3
Feb	-3.6	-16.0	7.5	82.3	40.9	25.3
Mar	0.5	-8.0	12.5	76.0	72.8	48.6
Apr	4.5	-6.0	19.1	75.1	109.3	64.5
May	9.4	-1.1	22.5	71.9	150.2	81.4
Jun	12.7	2.6	25.0	72.1	144.7	92.6
Jul	14.7	5.4	26.7	75.4	150.6	83.9
Aug	14.3	4.3	26.0	74.1	130.0	74.9
Sep	10.8	2.1	20.2	78.0	83.4	50.4
Oct	7.4	-1.0	17.2	79.9	57.9	33.7
Nov	2.6	-5.9	12.7	85.8	27.3	18.8
Dec	0.2	-10.9	10.9	85.9	17.8	12.9
Annual	5.9	-4.0	17.3	78.4	1008.8	603.2

2.2.2. Belgium - Brussels

Brussels lies 33m above sea level. Brussels has a significant amount of rainfall during the year. This is true even for the driest month. The climate here is classified as Cfb by the Köppen-Geiger system. Temperatures average 9.7 °C.

The rainfall is around 785 mm per year. The annual relative humidity is equal to 82.8 %. Table 2.7 shows monthly and annual value of ambient temperature, relative humidity and solar radiation in Brussels.

Table 2.7 - Brussels Climatic Data [13].

	T_{amb} mean [°C]	T_{amb} min [°C]	T_{amb} max [°C]	RH [%]	Gh [kWh/m²]	Dh [kWh/m²]
Jan	2.6	-8.4	12.0	88.2	20.2	14.2
Feb	3.2	-7.4	12.2	88.3	37.3	25.9
Mar	5.8	-3.3	16.7	83.4	66.5	42.3
Apr	8.6	-2.3	18.9	77.9	102.9	69.7
May	12.7	1.0	24.3	77.5	140.5	89.5
Jun	15.3	5.8	26.9	76.3	141.7	89.9
Jul	17.1	6.7	30.5	79.1	143.1	85.7
Aug	16.9	6.5	29.3	79.9	124.1	76.8
Sep	14.2	5.8	23.7	82.0	84.4	51.7
Oct	10.5	1.5	21.3	84.9	53.5	37.6
Nov	6.0	-3.2	15.2	88.6	24.7	16.2
Dec	3.7	-6.3	14.0	87.9	15.6	12.3
Annual	9.7	-0.3	20.4	82.8	954.6	611.9

2.2.3. Uppsala

The city of Uppsala is located in the Nordic climate zone (Dfc) [4,5], with cold, cloudy winter and cool, partially cloudy summer. The average annual temperature is 5.2 °C with average 1821 hours of sunshine annually. About 539 mm of precipitation falls annually during 248 days. On average, the warmest month is July with an average temperature of 16.2 °C, while the coolest month is February with an average temperature of -5.3 °C. The annual mean temperature is equal to 5.2 °C. The annual relative humidity is equal to 82.6 %. Table 2.8 shows monthly and annual value of ambient temperature, relative humidity and solar radiation in Uppsala.

Table 2.8 - Uppsala Climatic Data [13].

	T_{amb} mean [°C]	T_{amb} min [°C]	T_{amb} max [°C]	RH [%]	Gh [kWh/m²]	Dh [kWh/m²]
Jan	-3.9	-19.4	5.0	90.3	10.4	7.3
Feb	-5.3	-19.7	4.8	91.2	26.8	15.9
Mar	-1.6	-13.2	9.3	86.7	67.6	36.3
Apr	3.1	-7.8	14.6	79.4	108.5	57.9
May	8.8	-3.0	21.7	71.1	163.7	79.3
Jun	13.7	2.6	22.5	71.8	176.8	80.7
Jul	16.2	5.8	28.3	73.2	161.3	79.5
Aug	15.2	3.5	25.5	77.7	129.3	65.6
Sep	10.8	-0.3	21.7	82.2	76.9	42.8
Oct	6.5	-4.3	14.9	86.1	37.9	23.9
Nov	1.6	-8.4	11.1	90.3	13.6	9.3
Dec	-2.2	-16.9	6.7	91.0	7.4	5.3
Annual	5.2	-6.7	15.5	82.6	980.3	503.8

2.2.4. Heating/Cooling Degree Days

Heating Degree Days (HDD) index: It is defined as the severity of the cold in a specific time period taking into consideration outdoor temperature and average room temperature (in other words the need for heating). The calculation of HDD relies on the base temperature, defined as the lowest daily mean air temperature not leading to indoor heating. The value of the base temperature depends in principle on several factors associated with the building and the surrounding environment. By using a general climatological approach, the base temperature is set to a constant value of 15°C in the HDD calculation [14].

$$HDD = \begin{cases} \sum_i (18^oC - T_m^i), & if\ T_m^i \le 15^oC \\ 0, & if\ T_m^i > 15^oC \end{cases} \quad \text{2-1}$$

Cooling degree days (CDD) index: It is the severity of the heat in a specific time period taking into consideration outdoor temperature and average room temperature (in other words the need for cooling). The calculation of CDD relies on the base temperature, defined as the highest daily mean air temperature not leading to indoor cooling. The value of the base temperature depends in principle on several factors associated with the building and the surrounding environment. By using a general climatological approach, the base temperature is set to a constant value of 21°C in the CDD calculation [14]

$$CDD = \begin{cases} \sum_i (T_m^i - 21^oC), & if\ T_m^i \ge 24^oC \\ 0, & if\ T_m^i < 24^oC \end{cases} \quad \text{2-2}$$

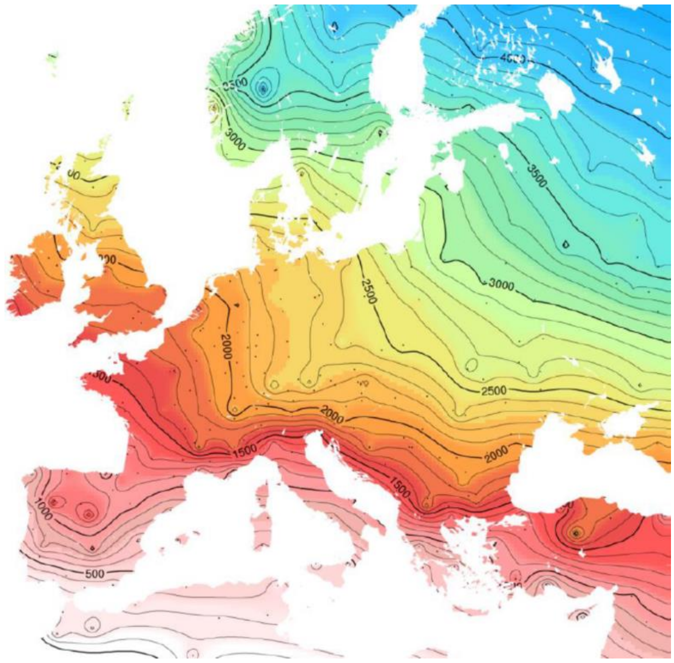

Figure 2.11 - Heating degree day – base 15 in Europe [9].

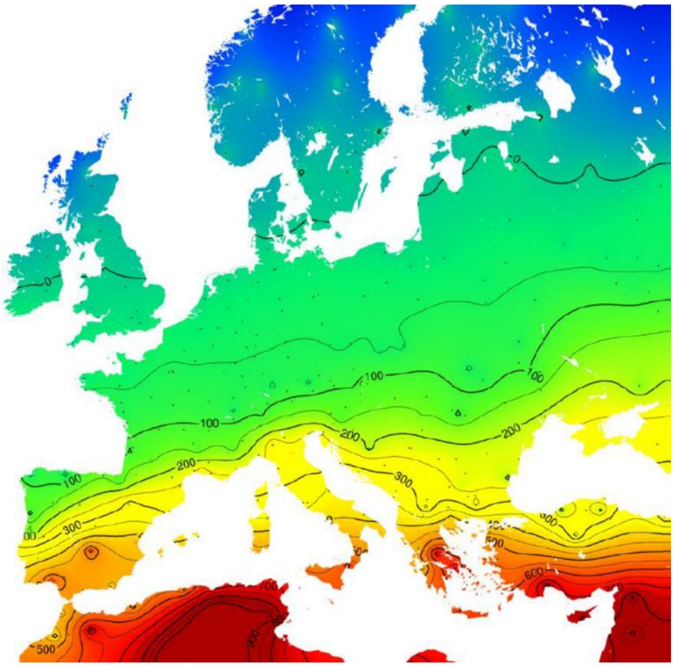

Figure 2.12 - Cooling degree day – base 21 in Europe [9].

Table 2.9 summarizes the heating and cooling degree days for the four target countries, according to Eurostat, based on 2018 data [15].

Table 2.9 - Heating/Cooling degree days for target countries (2018 data) [15].

Target country	Heating degree days	Cooling degree days
Belgium	2513.9	33.1
Germany	2775.8	51.2
Greece	1382.7	306.2
Sweden	5162.8	4.5

2.3. General Comfort related requirements and standards

Indoor environment (temperature, ventilation and lighting) affects not only the energy consumption of buildings, but also the health, productivity and comfort of the occupants. ISO 7730 defines the thermal comfort as the condition of mind which expresses satisfaction with the thermal environment [16]. The environmental conditions required for comfort are not the same for everyone, because of the large variations from person to person. Extensive laboratory and field data have been collected that provide the necessary statistical data to define conditions that a specific percentage of occupants will find thermally comfortable.

The existing national and international standards with technical reports, are used to determine criteria for thermal environmental conditions and air quality in a space that are necessary to achieve acceptance by a specific percentage of occupants of that space. Table 2.10 summarizes the fundamental standards regarding the comfort conditions.

Table 2.10 – Fundamental standards regarding the comfort conditions.

Standard	Title
EN 15251	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment lighting and acoustics
ASHRAE 55	Thermal Environmental Conditions for Human Occupancy
ISO 7730	Ergonomics of thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
ASHRAE 62.1	Ventilation for Acceptable Indoor Air Quality

2.3.1. Thermal Environment

Design values for the indoor temperature for heating and cooling loads, which describe the thermal environment for an occupied space, are specified through criteria based on the thermal comfort indices. Predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) with assumed typical levels of activity and thermal insulation for clothing are described in EN ISO 7730 [16].

2.3.1.1. PMV

The Predicted Mean Vote - PMV is an index that predicts the mean value of the votes of a large group of persons on a seven-point sensational scale (Table 2.11), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss heat to the environment. In a moderate environment, the human thermoregulatory system will automatically attempt to modify skin temperature and sweat secretion to maintain heat balance.

Table 2.11 - Seven-point thermal sensation scale [16].

Point	Sensation scale
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

The PMV model uses heat balance principles that relate six key factors for thermal comfort. These primary factors are:

1. Metabolic Rate- M [W/m^2]
2. Clothing Insulation- I_{cl} [m^2.K/W], t_{cl} [°C] and f_{cl} [-]

3. Air temperature - t_a [°C]
4. Mean radiant temperature – $\bar{t}_r$ [°C]
5. Relative air velocity - v_{ar} [m/s]
6. Humidity – RH [%] and p_a [Pa]

The determination of PMV with the use of these factors is described in ISO 7730, using the following equations:

$$\begin{aligned} PMV = {} & [0.303 \cdot \exp(-0.036 \cdot M) + 0.028] \\ & \cdot \{(M-W) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M-W) - p_a] - 0.42 \\ & \cdot [(M-W) - 58.15] - 1.7 \cdot 10^{-5} \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) - 3.96 \\ & \cdot 10^{-8} \cdot f_{cl}[(t_{cl}+273)^4 - (\bar{t}_r + 273)^4] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\} \end{aligned} \quad \text{2-3}$$

where,

$$t_{cl} = 35.7 - 0.028 \cdot (M-W) - I_{cl} \cdot [3.96 \cdot 10^{-8} \cdot f_{cl}(t_{cl} + 273)] \quad \text{2-4}$$

$$h_c = \begin{Bmatrix} 2.38 \cdot |t_d - t_a|^{0.25} & for & |t_d - t_a|^{0.25} > 12.1 \cdot \sqrt{v_{ar}} \\ 12.1 \cdot \sqrt{v_{ar}} & for & |t_d - t_a|^{0.25} < 12.1 \cdot \sqrt{v_{ar}} \end{Bmatrix} \quad \text{2-5}$$

$$f_{cl} = \begin{Bmatrix} 1.00 + 1.290 \cdot I_{cl} \; for \; I_{cl} \leq 0.078 \dfrac{m^2K}{W} \\ 1.05 + 0.645 \cdot I_{cl} \; for \; I_{cl} > 0.078 \dfrac{m^2K}{W} \end{Bmatrix} \quad \text{2-6}$$

As it is described in ISO 7730, PMV can be determined using one of the following ways:

a) through equations (Annex D of the standard)

b) directly from tables with values given for different combinations of activity, clothing, operative temperature and relative velocity (Annex E of the standard)

c) direct measurement, using an integrating sensor (equivalent and operative temperatures).

2.3.1.2. PPD

The Predicted Percentage Dissatisfied - PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm, as determined from the PMV. The PPD is calculated as a function of the PMV, using the following equation (Figure 2.13):

$$PPD = 100 - 95 \cdot exp(-0.03353 \cdot PMV^4 - 0.217 \cdot PMV^2) \quad \text{2-7}$$

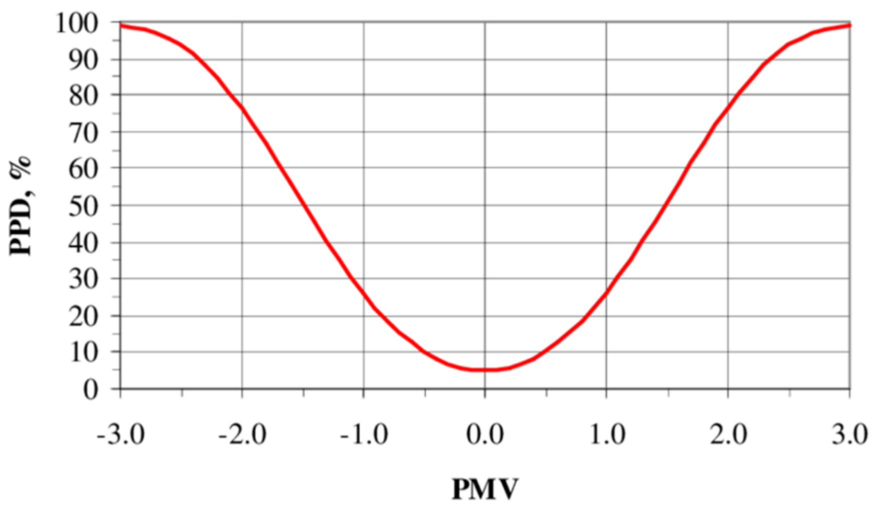

Figure 2.13 – PPD as function of PMV [16].

Recommended PPD ranges are given in the Table 2.12. PMV-PPD index takes into account the influence of all above six parameters (clothing, activity, air temperature, radiant temperature, air velocity, humidity) and can be directly used as criteria.

Table 2.12 - Examples of recommended categories for design of mechanical heated and cooled buildings [17].

Category	Thermal state of the body as a whole	
	PPD (%)	Predicted Mean Vote
I	<6	-0.2<PMV<+0.2
II	<10	-0.5<PMV<+0.5
III	<15	-0.7<PMV<+0.7
IV	>15	PMV<-0.7 or +0.7<PMV

2.3.2. Local thermal discomfort

The PMV and PPD express warm and cold discomfort for the body as a whole. But thermal dissatisfaction can also be caused by unwanted cooling or heating of one particular part of the body. This is known as local discomfort. The reasons for local thermal discomfort are, a) draught, b) the abnormally high vertical air difference between the head and the ankles, c) the too warm or too cool floor, and d) the too high radiant temperature asymmetry.

2.3.2.1. Draught

The discomfort due to draught is expressed as the percentage of people predicted to be bothered by draught. The draught rate (DR) is calculated using the following equation:

$$DR = (34 - t_{a,l})(\bar{v}_{a,l} - 0.05)^{0.62}(0.37 \cdot \bar{v}_{a,l} \cdot T_u + 3.14)$$

$$for\ \ \bar{v}_{a,l} < 0.05\, m/s\, , use\ \bar{v}_{a,l} = 0.05\ m\ /\ s \qquad \text{2-8}$$

$$for\ \ DR > 100\%\, , use\ DR = 100\%$$

Where

$t_{a,l}$ s the local air temperature, from 20°C to 26°C

$\bar{v}_{a,l}$ is the local mean air velocity, <0.5m/s

T_u is the local turbulence intensity, from 10% to 60%.

2.3.2.2. Vertical air temperature difference

A high vertical air temperature between head and ankles causes discomfort. To determine the percentage dissatisfied (PD) the following equation is been used.

$$PD = \frac{100}{1 + \exp\left(5.76 - 0.856 \cdot \Delta t_{a,v}\right)}\ \text{, for }\ \Delta t_{a,v} < 8^{o}C \qquad \text{2-9}$$

where $\Delta t_{a,v}$ is vertical temperature the difference between head and feet, °C

Figure 2.14 gives the PD of dissatisfied occupants as a function of the air difference where the head level is warmer than the ankle level. The opposite direction of thermal stratification is rare.

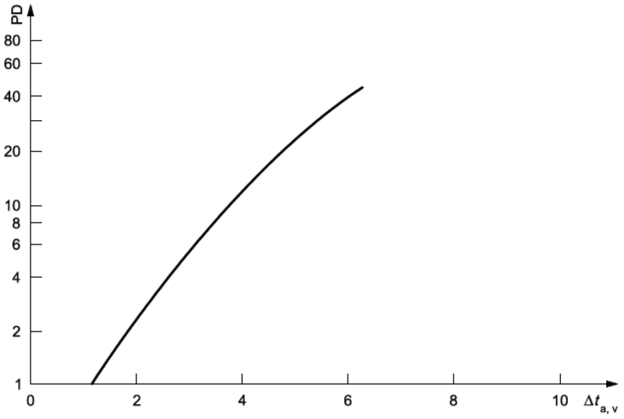

Figure 2.14 - Local Thermal discomfort caused by vertical temperature differences [16].

2.3.2.3. Floor Surface Temperature

Occupants may feel uncomfortable if the floor surfaces are too warm or too cold. The temperature of the floor (t_{fl}) is an important thermal factor for people wearing light indoor shoes. The following figure shows the predicted percentage of dissatisfied occupants as a function of floor temperature, based on studies with standing people.

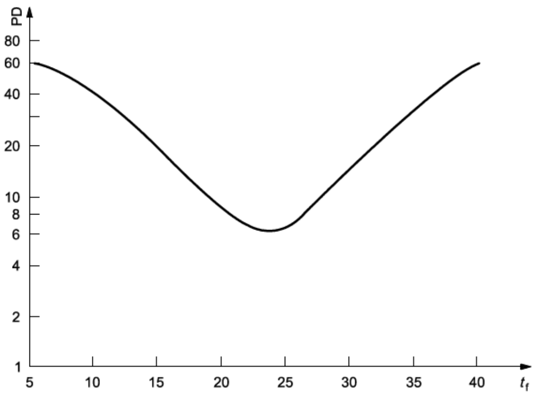

Figure 2.15 -Local thermal discomfort caused by difference in floor surface temperature [16].

For people sitting or lying on the floor, similar values can be used. The PD can be determined by using the following equation, derived from the original data using non-linear regression analysis

$$PD = 100 - 94 \cdot \exp(-1.387 + 0{,}118 t_f - 0.0025 t_f^2) \qquad \text{2-10}$$

2.3.2.4. Radiant Temperature asymmetry

Thermal radiation that affects the human body may be non-uniform due to hot and cold surfaces and direct sunlight. People are more sensitive to asymmetric radiation caused by a warm ceiling than that caused by hot and cold vertical surfaces. Figure 2.16 gives the predicted percentage of dissatisfied occupants (*PD*) as a function of the radiant temperature asymmetry (ΔT_{pr}) caused by a warm ceiling (1), a cool wall (2), a cool ceiling (3) or by a warm wall (4).

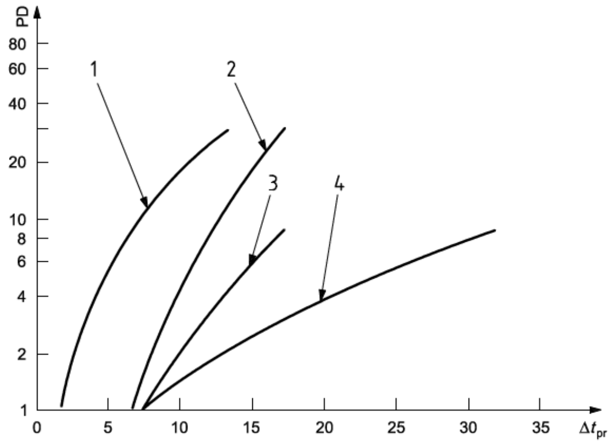

Figure 2.16 - Local thermal discomfort caused by radiant temperature differences [16].

PD can be determined also, by using the following equations:

1. Warm ceiling

$$PD = \frac{100}{1+\exp(2.84-0.174\cdot\Delta t_{pr})} - 5.5, \Delta t_{pr} < 23^{o}C \qquad \text{2-11}$$

2. Cool wall

$$PD = \frac{100}{1+\exp(6.61-0.345\cdot\Delta t_{pr})}, \Delta t_{pr} < 15^{o}C \qquad \text{2-12}$$

3. Cool ceiling

$$PD = \frac{100}{1+\exp(9.93-0.50\cdot\Delta t_{pr})}, \Delta t_{pr} < 15^{c}C \qquad \text{2-13}$$

4. Warm wall

$$PD = \frac{100}{1+\exp(3.72-0.052\Delta t_{pr})} - 3.5, \Delta t_{pr} < 35^{o}C \qquad \text{2-14}$$

2.3.3. Categories of Thermal environment

An acceptable thermal environment for an occupied space can be selected by three categories, A, B and C according to the Table 2.13. All the criteria must be satisfied simultaneously for each category.

Table 2.13 - Categories of thermal environment [16].

Category	Thermal state of the body as a whole		Local discomfort			
				PD % caused by		
	PPD %	PMV	DR %	Vertical air temperature difference	Floor surface temperature	Radiant asymmetry
A	<6	-0.2<PMV<+0.2	<10	<3	<10	<5
B	<10	-0.5<PMV<+0.5	<20	<5	<10	<5
C	<15	-0.7<PMV<+0.7	<30	<10	<15	<10

Table 2.14, Table 2.15 and Table 2.16 give values for the local thermal discomfort factors as described before (vertical air temperature difference, floor surface temperature and radiant temperature asymmetry).

Table 2.14 - Vertical air temperature difference between head and ankles [16].

Category	Vertical air temperature difference °C
A	<2
B	<3
C	<4

Table 2.15 - Floor surface temperature range

Category	Floor surface temperature range °C
A	19 to 29
B	19 to 29
C	17 to 31

Table 2.16 - Radiant temperature asymmetry [16].

Category	Radiant temperature asymmetry °C			
	Warm ceiling	Cool Wall	Cool ceiling	Warm wall
A	<5	<10	<14	<23
B	<5	<10	<14	<23
C	<7	<13	<18	<35

2.3.4. Design criteria for different types of space

The determination of operative temperature and mean air velocity ranges is essential for the thermal comfort analysis. Criteria for the operative temperature are based on typical levels of activity, for clothing 0.5 clo[2] during "cooling season" and 1.0 clo during "heating season". The criteria for the mean air velocity are applied for the turbulence intensity ca 40% (mixing ventilation). Table A.5 of ISO 7730 gives example design criteria for spaces in various types of buildings [16].

2.4. Requirements of non-residential buildings regarding daylight, interior lighting

2.4.1. Introduction to lighting and lighting quality

The role of lighting in building is to offer the adequate level and quality of illumination for the execution of the specific tasks under consideration. The lighting can come either from artificial light sources or from the utilization of the daylight or in best practices the combination of the two sources. Lighting for areas where human beings are the main or the only users is defined as the so called *Human Centric Lighting* (HCL). HCL comprises a holistic approach of the visual needs as well as the physiological and biological aspects of each task. Modern lighting design techniques mandate the use of the state-of-the-art technology in order to deliver an optimized lighting experience to the users of building as well as outdoor areas.

The HCL concept comprises of the following three aspects:

a) Visual light effect

This parameter refers to the quantitative and qualitative indices of lighting and it is strongly depended to the visual task under consideration. This is the legacy parameter that dominated the core lighting design effort since years. For each lighting task a set of minimum illumination levels, minimum uniformities, glare ratings, etc. The most important document to consult such levels, regarding non-residential buildings, is the European standard EN12464 *Lighting of work places – Part 1: Indoor work places* [18]. Therefore, in the process of the lighting design the lighting system should be able to achieve the minimum requirements that are defined by the EN standard and are related to the specific visual task.

[2] 1 clo = 0.155 m^2K/W

b) Emotional light effect

The scope of the emotional light parameter is to enhance social environment of the building users. Lighting designers have to take into account criteria based on architectural aesthetic and perception psychology aspects and on the user's needs or requirements. These criteria follow rules and interdisciplinary guidelines arising from good practice and cannot be well defined by regulations or standards.

c) Biological light effect

The biological light effect is a parameter that deals with the circadian rhythm of the user and aims to serve as best as possible to the maintenance of a human accepted day-around biological clock. As the circadian rhythm can affect the productivity of the human during the day period and the relaxation strength during night-time, it is crucial that the lighting system will respect this effect and consequently enhance the biorhythm of the building users.

In order for all the above parameters to actively serve the purpose the triangle of the optimized lighting design, commissioning and proper operation should be applied. Most of the modern lighting design techniques take advantage of the lighting equipment technology that let the illumination levels to be controlled (increased or decreased), that can also change the colour temperature of the emitted light (warn, neutral, cool, etc.) and to control individual lighting fixtures (luminaires) with ease and ever remotely.

On the other hand, the utilization of the daylight is also taken into account as either the main or the complementary lighting source. The amount of daylight that can be harvested depends on the configuration of the room the openings and the applied control system. Special daylight sensors can be installed in various positions inside the rooms in order to sense the daylight levels and control the luminaires accordingly. The combination of artificial light and daylight can lead to significant energy savings and optimization of the visual comfort while maintain the quality of the lighting and serve the concept of human centric lighting.

2.4.2. Requirements for indoor lighting

Non-residential buildings host in most cases various activities that can be linked one or more distinctive visual tasks. For example, lighting for office spaces differs in needs and quality figures compared to the hospital lighting or from the lighting for school rooms. As mentioned, the most important document and the main source of such information is for Europe the European standard EN 12464. This standard includes the lighting design techniques and the calculation methods for both indoor areas (Part 1) [18] and outdoor areas (Part 2) [19]. EN 12464 is only valid for non-residential places and refers only to work areas (in a wider perspective). Therefore, for the non-residential buildings one should use the EN12464-1 and apply the corresponding lighting requirements (profiles) to each indoor working space that wants to illuminate. This standard is well adopted in all European countries, while in some of them some minor deviations (especially in illumination levels) are proposed for the corresponding domestic market.

The main aspects of an optimized lighting design and operation define the luminous environment of the illuminated spaces. These parameters are also defined in the standard EN 12464 and followed in many national or other technical guides

The main target of the illumination is to serve the visual need of the user under a specific task. The parameters of the luminous environment are:

- the illuminance levels (defined and measured in lx) per task area
- the luminance distribution around the room
- the directionality of light (especially in cases of strong daylight and directional luminaires,
- the colour rendering of the used lighting sources
- the limitation of the glare
- the limitation of the lighting flicker.

By combining the above, the lighting designer sets the requirements or the so called "lighting profile" of the room under consideration. For several of the above parameters a set of specific requirements are defined as described below.

2.4.2.1. Luminance distribution

The luminance is the quantity of light that the human eye can see and perceive. Therefore, the distribution of the luminance around the room and the task areas plays a significant role to the visual comfort of the end user. Well balanced luminance distribution can increase the visual acuity, the contrast (i.e. the discrimination of the various objects and surfaces) and the efficiency of visual related tasks

What should be avoided in terms of the luminance distribution is the very high luminance values that lead to glary conditions, extreme contrast on objects that leads to eye fatigue and too low illuminated areas that hardens the ability of the user to perform his task.

Some quantitative recommendations related to the visual comfort are the reflectance of the surfaces that should be over 70% for ceiling, over 50% for walls and over 20% for the floor. In addition, a minimum amount of illuminance levels should be achieved on the walls (>50lx) and the ceiling (>30lx) in order to achieve an adequate luminance result.

2.4.2.2. Illuminance task areas and additional surfaces

The illuminance levels on the task areas are the most common and widely understandable metric of the indoor illumination. The relevant lighting guides, standards and regulations define at least some minimum illumination levels accompanied by the minimum overall uniformity (min/average). The defined levels are the maintained ones, means that at any point of the lifetime of the installation the illumination should not be below these limits. Illumination levels are defined for each task area, the immediate surrounding area and the background area. Figure 2.17 shows an example of the definition of these distinctive illumination areas according to the EN 12464.

For each of these areas, a specific level of illuminance and a minimum uniformity are required. The definition of the illumination areas is described in the relevant standards (e.g. EN 12464) and must be followed during the lighting design phase. The selection of the types and the positions of the luminaires should take into account the fulfilment of the requirement of each defined area.

In order to achieve a perceptual difference, the lighting levels of the relevant areas should differ by a certain amount that depends on the level of illumination. For example, one should use the levels of 50 – 75 – 100 – 150 – 200 – 300 – 500 etc. If the lighting levels of areas with different needs have very similar illumination levels then they will be hard to distinguish or the visual guidance will be weak.

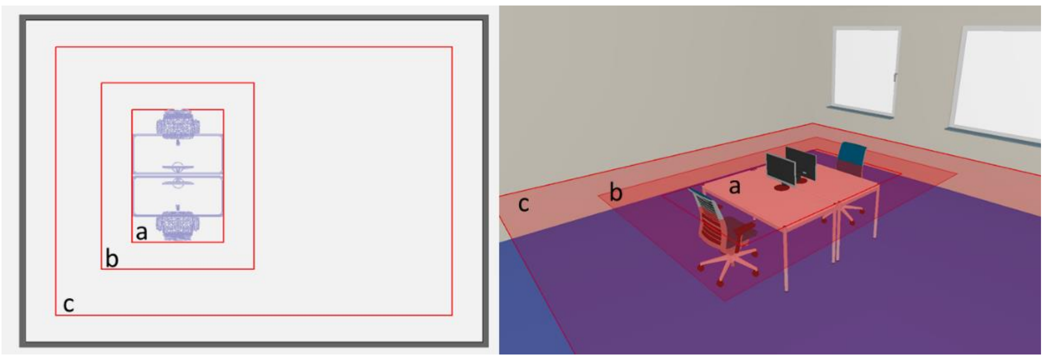

Figure 2.17 - Example the illumination areas of an office room: a) main task area, b) surrounding area and c) background area of room.

The illumination of the immediate surrounding areas should be a step below the illumination of the task area, while the background area should be illuminated as much as needed for the purpose. The connection of the illumination of the additional areas follows some rules and are shown as an example in Table 2.17.

Table 2.17 - Example of the relationship of illuminances on immediate surroundings to the illuminance on the task area and background areas.

Task area (lx)	Immediate surrounding areas (lx)	Background areas (lx)
> 750	500	1/3 of task area
500	300	1/3 of task area
300	200	1/3 of task area
200	150	1/3 of task area

2.4.2.3. Cylindrical illuminance

The cylindrical illumination is defined as the level of illumination that reaches the surface of a virtual cylinder placed vertically at various room positions at a certain height. This special type of illuminance (also measured in lx) refers to the illumination of people, faces and objects in a room that enhances the visual communication and facial recognition. Cylindrical illumination is very important in various indoor areas like offices, schools, meeting areas, etc. As for the required level, in most cases, 50 lx of cylindrical illumination is considered as satisfactory.

2.4.2.4. Illuminance calculation and verification grids

One of the most important factors of the lighting design process and the verification of the achieved results is the illuminance calculation grid of each room, task areas, walls, ceiling, etc. It applies to both artificial and daylight and according to EN 12464 should be the same grid of calculation and of measurements (verification). The grid comprises of predefined points of calculation / measurements for which the average, maximum, minimum values of illuminance and the quality indices are derived. Figure 2.18 shows some examples of the calculation grids.

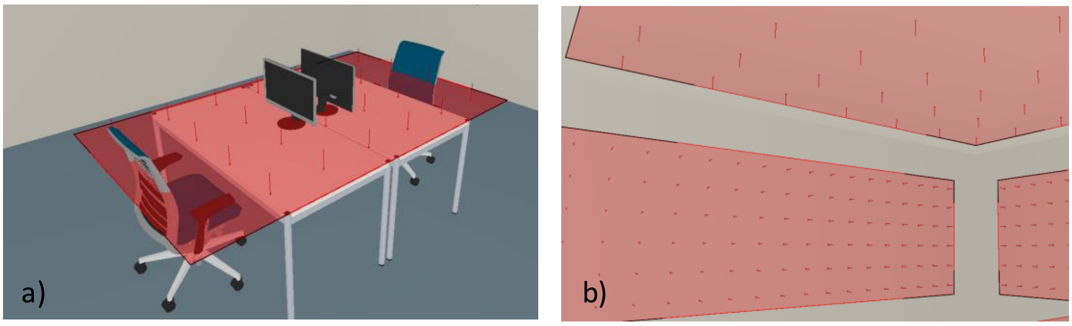

Figure 2.18 -Example the calculation grids a) on the task area (left) and b) on the walls and ceiling (right).

2.4.2.5. Glare restriction

The glare is produced by a combination of very bright areas within the field like illuminated surface, luminous surfaces of the luminaires, windows and roof lights. The glare should be controlled in order to avoid disturbance, fatigue and more importantly potential accidents at work. The specific glare that is produced by specular reflections is also known as *reflected glare*. In cases of the visual field in mainly directed above the horizon, the glare restriction is of high importance in lighting design. There are two types of glare. The discomfort glare and the disability glare.

Disability glare is a level of the annoyance that is produced by high levels of luminance in the visual field. According to the International Lighting Vocabulary (ILV, term 17-330) [20], disability glare is the glare that impairs the vision of objects without necessarily causing discomfort. On the other hand, discomfort glare (ILV, term 17-333) is the glare that causes discomfort without necessarily impairing the vision of objects.

The rating of the discomfort glare caused by the luminaires can be calculated by the following equation. The maximum permitted value of the UGR depends on the visual task.

$$UGR = 8\log_{10}\left(\frac{0.25}{L_B}\sum\frac{L^2\omega}{p^2}\right) \quad 2\text{-}15$$

where:

- L_B: is the background luminance (in cd/m^2), calculated as $E_{ind}\cdot\times\pi^{-1}$, in which E_{ind} is the vertical indirect illuminance at the observer's eye,
- L: is the luminance (in cd/m^2) of the luminous parts of each luminaire in the direction of the observer's eye
- ω: is the solid angle (in steradian) of the luminous parts of each luminaire at the observer's eye,
- p: is the Guth position index for each individual luminaire which relates to its displacement from the line of sight.

Glare rating related to the contribution of the windows is not yet developed nor commonly agreed. In these cases, care should be taken in order to minimize the luminance levels of the windows in order to achieve the visual comfort of the users.

Various methods are proposed to reduce the UGR value in cases where its value is higher that allowed. Shielding of the luminaires at specific angles is one of the most common methods, while the material and the colour of the illuminated surface can also degrease the glare effect.

2.4.2.6. Flicker restriction

Flicker from light sources is defined as the impression of unsteadiness of visual perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time (ILV, term 17-443) [20]. Flicker is only produced by the artificial light sources not by daylight. In general, flicker can be noticeable by human vision (clearly visible) or non-noticeable. In the first situation, the flicker causes a disturbance to the user that can produce fatigue up to epilepsy in persons that are sensitive to this effect. On the other hand, the non-visual flicker can cause similar problems to the human especially those who are related to the vision system, the brain and the mental state.

The indirect effect of flicker in human vision can be also the stroboscopic effect in objects that move fast enough, where the object seems to jump from position to position without indorenate states. In addition, long term flicker (in terms of minutes) can produce significant effect to the human brain (like headaches) due to the high frequency components of the emitted light.

The flicker can be measured and can be reduced by considering the installation of low flicker lighting products. Figure 2.19 shows two examples of the measured waveforms of the emitted light from real lighting products. The one shows low flicker and the other high enough that in some cases can be noticeable by naked eye. In general, lighting systems should be designed to avoid flicker and stroboscopic effects

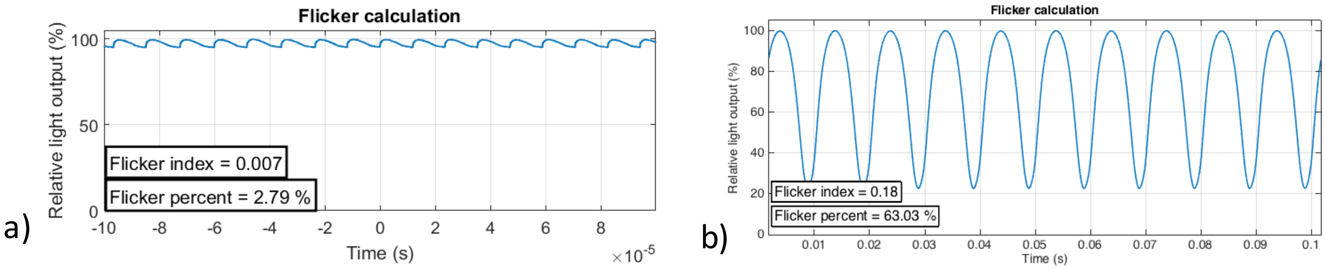

Figure 2.19 - Examples of flickering light waveforms, a) low flicker (left), b) high flicker (right).

2.4.2.7. Colour of light

The colour of the emitted light, either artificial or daylight, plays a significant role in the implementation of the HCL concept and the optimization of the visual comfort. By definition, the colour appearance can be grouped in three main groups.

a. warm – colour temperature below 3300K
b. intermediate – colour temperature between 3300K and 5300K
c. cool – colour temperature above 5300K

The above grouping is not strict nor the only one. Several groups are proposed and used in order to define which colour temperature is considered warm/cool/neutral etc. The selection of the colour temperature is essential for the psychology the aesthetics and what is considered to be natural. The choice depends on many parameters like the illuminance level, the use of the room, the colours of the room, the location, etc. This refers only to static illumination schemes. In case of the adaptive colour temperature (HCL approach) more than one colour temperature can and should be used as will described in a next section.

Lamps and luminaires can produce a variety of colour temperatures. All traditional artificial light sources can produce only one colour temperature at the time (depended on the specific model), while LED technology can produce variable colour temperatures by mixing the LED chips in one lighting module and so on.

Daylight has also non-static colour temperature. This is why humans and the environment in general are programmed to follow the circle of the day. The transition of the morning to the noon and to the evening is followed by cool, neutral and warm colour temperature respectively. This rhythm is what HCL is trying to mimic through the variable colour temperature scheme. Figure 2.20 shows a variety of colour temperatures that stretch from 1000K up to 10000K.

Figure 2.20 - Light sources with various colour temperature from 1000K to 10000K.

2.4.2.8. Colour reproductivity (colour rendering)

Colour rendering is essential for the reproductivity of colours and is linked to the colour temperature. Very high and very low colour temperatures may lead to poor colour quality while natural colour temperatures tent to reproduce the colours in a good way. The latter in not restrictive to various light sources that can either have good or bad colour rendering capabilities. Several light sources can reproduce the colours accurate enough. The desired level of colour reproductivity depends on the visual task that is under consideration.

The common metrics for the colour rendering are the colour rendering index (CRI), the full-spectrum index (FSI); the full-spectrum colour index (FSCI) and the colour gamut area (GA). Each colour rendering metric emphasizes a slightly different aspect of colour rendering. Figure 2.21 shows some examples of the different effect of light sources in the colour reproduction of a set of various colour targets.

Figure 2.21 - Reproduction of colours under a) 2200K, b) 4000K and c) 6500K.

2.4.2.9. Requirements of common working areas

The above described criteria, parameters and metrics are applied to each individual working area / room / building or other defined area under illumination. The EN 12464-1 includes the requirements of all kind of working areas. As an example of this standard requirements, Table 2.18 shows the limits for some common areas in buildings.

Table 2.18 - Limited example of lighting requirements for certain areas according to the EN 12464-1 [21].

Usage	Illuminance Em [lx]	Uniformity Uo	Glare ratio UGRL	Colour rendering Ra
Offices				
Filing, copying, etc.	300	0.40	19	80
Writing, typing, reading, data processing	500	0.60	19	80
Technical drawing	750	0.70	16	80
CAD workstations	500	0.60	19	80
General areas inside buildings				
Circulation areas and corridors	100	0.40	28	40
Stairs, escalators	100	0.40	25	40
Elevators, lifts	100	0.40	25	40
Loading ramps/bays	150	0.40	25	40

2.4.3. Daylight harvesting

Daylight is one of the two alternative sources of illumination for buildings. Daylight comes in various amounts of lighting energy that depend on the time of the day the orientation of the area/building, the location on the globe (longitude/latitude), the season and the weather conditions. Therefore, daylight is a fully incontrollable light source that in most cases can deliver adequate amount of light but not always from a convenient direction and elevation.

During the design of a building, the harvesting of daylight is one of the main considerations. The utilization of the free daylight can be done through envelope openings like windows, skylights, sun pipes, etc. This will lead to a decreased demand for artificial light especially in building where the main use is during daytime. However, the utilization of daylight demands detailed design of a building and an adaptive lighting control system that comprises of dimmable luminaires and light sensors.

The potential for daylight harvesting can be predicted using the building geometry and its orientation, the location and the statistical daylight data of the area. Specific methods defined in various standards with the most commonly used the EN 15193:2017 “Energy performance of buildings - Energy requirements for lighting” [22]. In brief, the daylight potential is estimated via the calculation of specific factors. The general calculation model relies on the geometry of the rooms and the daylight zones. Figure 2.22 illustrated two typical room geometries, one with large openings compared to the façade area (high Window to Wall Ratio – WWR), the height of the openings and the depth of the room. In such a way, the daylight zones and non-daylight zones can be defined. In a similar way, daylight zones can also be defined by skylights and sun pipes.

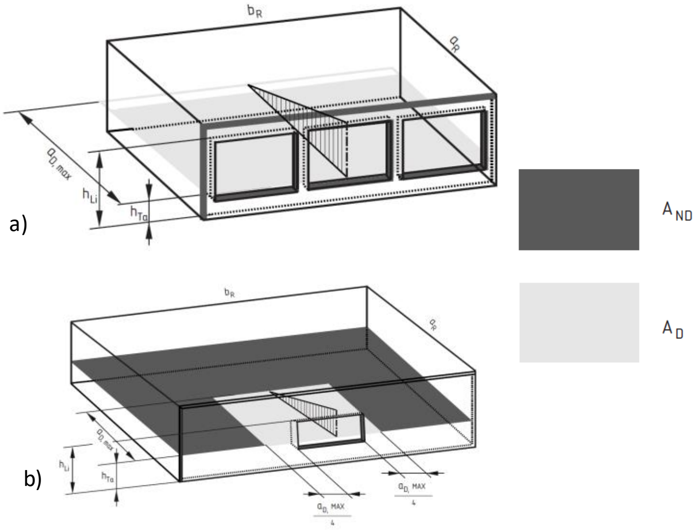

Figure 2.22 - Definition of daylight zones using modelled rooms with a) high and b) low WWR.

2.4.4. Daylight factor

The daylight factor is defined as the ratio of the illuminance at a point on a given plane due to the light received directly and indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, where the contribution of direct sunlight to both illuminances is excluded (ILV, term 17-279). This is one of the most important and widely used factors for the determination of the daylight potential in an internal space. The general rule for the daylight factor in terms of the daylight penetration is shown in Table 2.19. Additional calculation-specific daylight factors that need to be calculated in order to estimate the energy saving potential are the following:

- External daylight factor
- Constant illuminance factor
- Daylight dependency factor
- Daylight supply factor
- Occupancy dependency factor

Table 2.19 - Light penetration as function the daylight factor.

Daylight factor D	Daylight penetration
D > 3%	Strong
3% > D ≥ 2%	Medium
2% > D ≥ 1%	Weak
1% < D	None

In order to get benefit from the daylight penetration in the interior spaces, two ways of control are currently available. The first refer to the control of the artificial light in order to balance the mix between daylight and artificial light and the second belongs to the active control of the widow’s blinds, external sun shelves, etc. The control methods are described in the next section.

2.4.5. Lighting management and lighting controls

The aim of the lighting management system is to deliver an optimized illumination result to the space under control taking into advantage the artificial lighting equipment and the daylight harvesting systems. Various control systems aim to only control the artificial light while many can incorporate daylight sensors and the corresponding control capabilities.

Light management systems can serve the following needs:

- Deliver the required lighting levels to all room areas throughout the day and the lifetime of the lighting equipment
- Follow the concept of HCL by the variation of the lighting levels and the colour temperature along the daytime in order to follow the circadian rhythm and other requirements
- Take advantage of the daylight penetration in the room by regulation the artificial lighting in order to achieve the desired illumination levels with the less possible energy consumption
- Monitor the quality of the delivered illumination and fine-tune the lighting system
- Monitor the operational parameters of the light equipment and optimizing their lifetime
- Integrate with the Building Management System (BMS)

Using lighting control systems, the building illumination can be preprogramed with various profiles related to a specific use of a room (e.g. meeting room with different lighting profiles), time of the day, special occasions, etc. This leads to a control scheme beyond the traditional on/off or the manual switching of groups of luminaries.

Some typical control schemes that can be implemented in building automation are.

a) Control of a luminaire group on the same level of dimming according through manual control using a dimming switch of a control console

b) Basic automatic control of a group of luminaires via a daylight sensor placed in the room. The daylight sensor is measuring the amount of daylight and gives a feedback in the control system

c) Intermediate automatic control of groups of luminaires using the previous concept but taking into account the feedback of multiple sensors in the room either over working areas or from sensors directed towards the windows

d) Advanced automatic control which can control each luminaire individually (specific lighting output for each luminaire) and apply complex algorithms in order to achieve the desired levels of illumination. These control systems take advantage of the daylight by using the input of the various sensors (daylight, occupancy, motion, thermal, etc.).

e) Human Centric Lighting management system which offers the functionality o the advance automatic control plus the application of the light levels variation and colour temperature variation according the HCL needs.

The means of control in a lighting management system are grouped in the following categories.

- Luminaires: The luminaires could be only on/off capable (traditional equipment) or controlled in terms of lighting output level (dimming control) and colour temperature control (only for specific LED equipped luminaires).
- Control gear: Is a set of control equipment like dimmable drivers/ballasts, communication hubs, translators, connectors with other systems, switches etc.
- Sensors: This is the heart of the control system is terms of sensing the environment. Sensors can be any kind of device that measures and reports a specific quantity that is needed for the management system to take the right decision for controlling the lighting system. Sensors are light sensors, motion sensors, occupancy sensors, infrared sensors, colour sensors, etc.

2.4.6. Summarized IGU requirements related to lighting and visual aspects

The IGUs under design and development should contribute to the fulfilment of the lighting related requirements that are described in sections 2.4.1 to 2.4.5 and summarized in the Table 2.20. It should be noted that the IGUs cannot directly fulfil the mentioned requirements but can significantly influence most of them in combination with daylight and the adaptive artificial lighting system.

Table 2.20 – Lighting and visual related requirements connected to the IGUs under development

Parameter	Typical value / range	IGU characteristic	Influence
Illuminance level at working plane	200 - 750 lx	Overall transmittance	Direct

Colour temperature of light entering the room	3000 – 6000K	Spectral transmittance	Direct
General colour temperature in the room	2700 - 5000K	Spectral transmittance	Indirect
Visual appearance of the IGU from inside (colour, hue, etc)	As neutral white as possible	Spectral transmittance and reflectance	Direct
Daylight factor of the room	> 2	Overall transmittance	Indirect
IGU respond to external control signal or daylight levels.	< 1min[3]	Speed of self-response of TC and speed of response on an external signal for the EC component	Direct

2.5. Energy saving standards for target countries (non-residential buildings)

After the establishment of the Energy Performance of Buildings Directive (EPBD), each Member State has to set minimum energy performance requirements for new buildings, and for the renovation of existing buildings with a view to achieving cost-optimal levels [5, 6]. At the same time, the Energy Performance Certification (EPC) is introduced in this Directive as the first step to gain an insight into the energy performance of existing buildings and improve the performance of new buildings. The following sections describe the national regulations for the energy performance of non-residential buildings for the four target countries (Belgium, Germany, Greece and Sweden). The most widely used window parameter used by national regulations is the thermal transmittance (or U-value). The accurate definition and the calculation methodology are described in section 2.6 (Table 2.40).

2.5.1. Belgium

In Belgium, the regulations regarding the building energy performance are set at the regional level: Brussels Capital, Flemish and Walloon region [23-25], as depicted in Figure 2.23. However, the three regions cooperate to establish a common methodology for new and refurbished buildings, leaving each region free to define its own requirements.

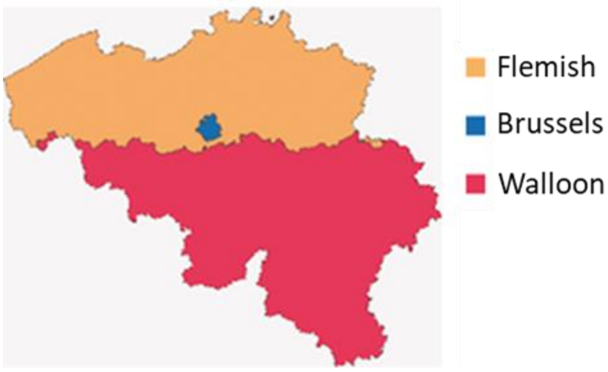

Figure 2.23 – The regions in Belgium.

2.5.1.1. Brussels region

The energy performance requirements have been mandatory for buildings for which the building permit has been requested after July 2008. The applicable energy performance requirements are on primary energy consumption, insulation level, ventilation rate, overheating, technical installation, etc. and are different for new buildings, major

[3] Indicative time of response from a given state of EC to a new dimming state. Shorter times will give better degree of freedom to the artificial lighting control system while longer times will delay the decision-making procedure.

or simple retrofits, and existing buildings. Only new units[4] or units assimilated to new buildings[5] which are designated as individual residential units (houses and apartments) and non-residential units (offices and service buildings, or educational buildings) have to respect all the energy performance requirements. These 3 types of units constitute the greater part of the building sector in the Brussels region, with a very significant share accounting for residential units. Units similar to new buildings are governed by the same requirements as new units, but have 20% more flexibility on some requirements. These requirements concern public buildings, as well as private.

The calculation procedure in Brussels region is defined in an execution order that was adopted on 21st February 2013. The method is similar to those established in the Flemish and the Walloon Regions. The calculation method for primary energy already includes the input of Renewable Energy Sources (RES), e.g., solar energy (thermal and photovoltaic), biomass heating, geothermal heating and heat pump systems, as well as passive cooling techniques. The NZEB definition is included in "The Brussels Air, Climate and Energy Code (COBRACE)". The 2015 in Brussels implemented "EPB Passive Requirements 2015" is the transposition of the nZEB definition, which is based on the Passive House Standard and adapted to the Brussels context.

At present, renovated buildings are only subject to specific requirements related to minimum values of insulation of the walls (U and R values). As of 1 January 2014, the U-value requirement was tightened. Table 2.21 summarises the U value requirement after 2014.

Table 2.21 - U-value requirement for the Energy Performance of Buildings (EPB) in the Brussels region after 2014 [23].

Main U-value requirement	U-value ($W/(m^2 \cdot K)$)
Roof	0.24
External walls (above ground)	0.24
Ground floor	0.3
Windows (U_w)	1.8
Curtain walls (U_{cw})	2.0
Glass (U_g)	1.1

Table 2.22 presents the requirements of new non-residential units (offices, services and schools).

Table 2.22 - Requirements for new non-residential units in the Brussels [23].

Requirements	Offices and services/schools
Net Heating energy Requirement (NHR) [6]	15 $kWh/(m^2 \cdot y)$
Net Cooling energy Requirement (NCR)	15 $kWh/(m^2 \cdot y)$
Primary Energy Requirement (PEC)[7]	95-(2.5°C) $kWh/(m^2 \cdot y)$ or (95-(2.5°C)) + (1.2·(X-15)) $kWh/(m^2 \cdot y)$
Airtightness	n50=0.6 Vol/h (requirement applied as of 2018)

As of July 2017, the requirement for the total primary energy consumption (PEC) is extended to all non-residential buildings (offices, schools, shops, healthcare facilities, courts, laboratories). For non-residential buildings, the PEC requirement is calculated according to equations 2-16 and 2-17:

$$\mathrm{PEC} = \frac{\sum_f A_{\mathrm{gross\ fct\ f}} \cdot \mathrm{PEC}_{\mathrm{max\ fct\ f,Uref}}}{A_{\mathrm{gross}}} \qquad \text{2-16}$$

[4] "Unit" = a set of adjacent rooms in one and the same building that can be sold or let independently and whose use comes within the scope of application of the EPBD.

[5] "Unit assimilated to a new-build" = a unit that had more than 75% of its sources of heat loss renovated and also had all its technical installations replaced.

[6] The "X" is an alternative requirement that has been designed for EPB-units whose poor orientation or compactness makes it unfeasible to enforce compliance with a net heating energy requirement of 15 $kWh/(m^2 \cdot y)$

[7] For primary energy consumption calculation purposes C is equal to the value of the compactness of the unit and cannot exceed 4.

$$\mathrm{PEC_{max\,fct\,f,Uref}} = \mathrm{Y} \cdot \mathrm{E_{spec\,ann\,prim\,en\,cons,ref}} \tag{2-17}$$

where, $E_{spec\ ann\ prim\ en\ cons,ref}$ is the primary energy consumption of the reference building/unit and Y is a value that will gradually decrease by 2021. For functions “offices”, “teaching” and “technical spaces” Y=0.6 and for all the other non-residential functions Y=0.9.

For new buildings, an Energy Performance Certification (EPC) is issued at the end of the process based on the final energy performance declaration. Table 2.23 presents the reference values determining the energy performance for non-residential buildings. The Energy class is calculated by dividing primary energy consumption by the gross surface area of the non-residential building.

Table 2.23 - Energy labels for non-residential buildings – Subclasses and consumption [23].

Energy class	Energy index: kWh_{EP}/m^2year	Energy class	Energy index: kWh_{EP}/m^2year
A+	less than zero	D+	from 249 to 279
A	from 1 to 31	D	from 280 to 310
A-	from 32 to 61	D-	from 311 to 341
B+	from 62 to 93	E+	from 342 to 372
B	from 94 to 124	E	from 373 to 403
B-	from 125 to 155	E-	from 404 to 434
C+	from 156 to 186	F	from 435 to 527
C	from 187 to 217	G	527 and above
C-	from 218 to 248		

2.5.1.2. Flemish region

Energy performance requirements for new and renovated buildings in the Flemish Region first started in January 2006. The legislation was consolidated in the energy decree of 2009 (het Energiedecreet van 8 mei 2009) and the energy law of 2010 (het Energiebesluit van 19 November 2010). Each new building must fulfil requirements on energy performance (E-level) and insulation (U-values and global insulation ‘K-level’) as well as on the indoor air quality and thermal comfort (risk of overheating and ventilation).

The most important requirement concerns the dimensionless E-level. The E-level is the level of global energy performance. It is the annual primary energy consumption divided by a reference consumption. The reference consumption for residential buildings is a regression formula based on the consumption of a set of buildings with reference measures in 2006.This level was set at E100. For non-residential buildings, the reference consumption is calculated on the same building geometry with a set of reference measures. The energy performance level or E-level sets the maximum allowed primary energy use for a building. The calculation includes, e.g., thermal bridges, shading devices and the infiltration rate. Table 2.24 presents the E-level requirements for different types of non-residential buildings.

Table 2.24 – Energy level tightening scheme for non-residential buildings in the Flemish region [24].

E-level, function	Requirements (2018)	Requirements (2021)
Lodging functions	70	70
Offices	55	50
Education	55	55
Healthcare with lodging	70	70
Healthcare without lodging	65	65
Healthcare operating rooms	50	50
Meeting areas high occupancy	65	65
Meeting areas low occupancy	65	65
Meeting areas cafeteria/refectory	60	60

Kitchens	55	55
Commerce	60	60
Sports: sports hall	50	50
Sports: fitness, dance	40	40
Sports: sauna, swimming pool	50	50
Technical plants/control rooms	45	45
Common areas	55	50
Other	80	80
Unknown	80	80
Public administration buildings		
Offices	50	50
Meeting areas high occupancy	65	65
Meeting areas cafeteria/refectory	60	60
Kitchens	55	55
Technical plants/control rooms	45	45
Common areas	50	50

Table 2.25 presents the required primary energy consumption for the new non-residential buildings.

Table 2.25 - Primary Energy Consumption for new non-residential buildings in the Flemish region.

Requirements as of 2017	Primary Energy Consumption (PEC) (kWh/(m²·y))
Existing buildings	108
Nearly Zero Energy Buildings (nZEBs)	40

There are no specific requirements for technical building systems for new residential and non-residential buildings. The performance of systems is integrated in the calculation methods of the energy performance (E-level). Since the performance of the installations is taken into account in the E-level, there is no need for individual requirements. Individual requirements for new buildings are therefore considered an extra administrative burden that in addition reduces freedom in design without a proportionate benefit. Since 2006, maximal U-values are in place for new building components (Table 2.26). These levels were systematically strengthened during the years and are meeting current cost-optimal levels.

Table 2.26 - Maximum U-value requirements since 2016 in the Flemish region [24].

Main U-value requirement	Maximum U-value (W/(m²·K))
Roofs, ceilings to attics	0.24
Outer walls	0.24
Floors on the ground, or above cellars	0.24
Windows (profile + glazing)	**1.50**
Glazing	**1.10**
Insulated existing walls (outside)	0.24
Insulated existing walls (cavity)	0.55
Insulated existing roofs	0.24
Insulated existing floors in contact with outdoor environment	0.24

2.5.1.3. Walloon region

Since January 2017, the level of regulatory requirements has been tightened. A new reinforcement corresponding to NZEB for public buildings was set on 1 January 2019 and for all other buildings is planned on 1 January 2021. An overview of the requirements is presented in Table 2.27 regarding the maximum U-values for a) the new and existing houses, collective housing, hospitals, offices and schools and b) the new and existing shops, catering buildings, sports facilities, business and industry.

Table 2.27 - U-value requirement for the Energy Performance of Buildings (EPB) in the Walloon region [25]

Main U-value (requirements applied as of January 2017)	U-value ($W/(m^2{\cdot}K)$)
Windows and other translucent walls, excluding doors, garage doors, curtain walls and glass brick walls	$U_{w,max}$ = 1.5 and $U_{g,max}$ = 1.1
Ceilings and roofs	0.24
Walls without any contact with the ground	0.24
Walls in contact with the ground	0.24
Vertical walls and sloping walls in contact: • With underfloor spaces • With cellars outside the protected volume	0.24
Floor in contact with the outside environment or above an underfloor space	0.24
Other floors: • Above a crawl space • Above a cellar outside the protected volume • Basement floors underground • Above the ground	0.24
Doors and garage doors	$U_{D,max}$ = 2.0
Curtain walls	$U_{cw,max}$ = 2.0 and $U_{g,max}$ = 1.1
Glass brick walls	2.0
Walls between 2 protected volumes located on adjacent spaces	1.0
Opaque walls inside a same protected volume or adjacent to another protected volume on the same property, except for doors and garage doors between industrial occupancy spaces and non-industrial occupancy spaces	1.0

Table 2.28 presents the required primary energy consumption for the new non-residential buildings.

Table 2.28 - Primary Energy Consumption for new non-residential buildings in the Walloon region.

Requirements as of 2017	Primary Energy Consumption (PEC) ($kWh/(m^2{\cdot}y)$)
Existing buildings	108
Nearly Zero Energy Buildings (nZEBs)	60

Until now, only residential buildings, schools, office buildings and services buildings were calculated in terms of overall energy performance. From 1 January 2017, this calculation is extended to all other non-residential types of building units (called PEN units). The threshold of the requirement for PEN units is variable (Table 2.29) and depends on the functional parts present in the unit and their respective sizes, according to the equation 2-18.

$$E_{W,PEN,max} = \frac{\sum_f A_{ch,fct\,f} \cdot E_{W,max,fcf\,f}}{A_{ch}} \tag{2-18}$$

Where:

- $E_{W,PEN,max}$ is the threshold for the E_W level of the studied PEN unit (dimensionless)
- $A_{ch,fct\,f}$ is the total heated floor area of each function f of the PEN unit (m^2)
- $E_{W,fcf\,f}$ is the assumed requirement level per function, for each function of the PEN unit (dimensionless)
- A_{ch} is the total heated floor area of the studied PEN unit (m^2)

Table 2.29 - The values of the requirement levels per function $E_{w,fcf\,f}$ [25]

Functions		$E_{W,fcf\,f}$ (2017)	$E_{W,fcf\,f}$ (2021)
Accommodation		90	90
Offices		65	45
Schools		65	45
Health care	With nocturnal occupation	90	90

	Without nocturnal occupation	90	90
	Operating room	90	90
Kitchen		90	90
Commerce		90	90
Sports hall/gymnasium		90	90
Fitness, dance		90	90
Sauna, pool		90	90
Technical local		65/90	45/90
Common		65/90	45/90
Other		90	90
Unknown		90	90

2.5.2. Germany

The Energy Saving Ordinance ("Energieeinspaarverordnung (EnEV)") is an important part of the energy- and climate politic of the German Government and describes minimum requirements regarding energy use of new and renovated buildings. Private and most commercial buildings have to be built according to the regulation to obtain a building license. The requirements are set to stricter standards in irregular intervals. On 1st May 2014 a new version of the ordinance came in to force as consequence of the "Second Ordinance amending the Energy Saving Ordinance of 18th November 2013" (EnEV 2013). The amendment partly serves for the implementation of the recast European Directive on Energy Performance of Buildings (2010/31/EU). The level of requirements was re-adjusted effective from 1st January 2016 in course of this amendment. Section 2 refers to buildings to be built, while section 3 refers to existing buildings and facilities. The following description of the German regulation refers mainly on those sections relevant to glazing and transparent components of envelopes of non-residential buildings.

Legislators demand in the current Energy Savings Ordinance 2016 (EnEV / EnEV 2016) that windows must reach certain minimum standards in terms of energy efficiency. How much energy a window transmits to the outside world is expressed by the U-value. In addition, the EnEV regulates how much solar radiation, described by the g-value (energy transmittance), a window should allow to pass. For non-residential buildings, the EnEV also demands a minimum light transmittance.

The Energy Saving Ordinance ENEV2013 is to be replaced by Building Energy Act (GEG 2019) according to the decision of the federal government of October 23, 2019. Section 2, § 4 of the Energy Saving Ordinance describes the requirements for new non-residential buildings:

(1) Non-residential buildings to be constructed shall be designed so that the annual primary energy requirements for heating, water heating, ventilation, cooling and built-in lighting are the annual primary energy demand of a reference building of the same geometry, net floor area, orientation and use, including the location of the units of use does not exceed the technical reference design specified in Table 2.30.
(2) Non-residential buildings to be constructed shall be designed so that the maximum U-values of the heat-transferring enclosure according to Table 2.31 are not exceeded.
(3) For the non-residential building to be constructed and the reference building, the annual primary energy demand shall be calculated in accordance with one of the procedures set out in Annex 2 of the regulation. The non-residential building to be constructed and the reference building shall be calculated using the same procedure.
(4) Non-residential buildings to be constructed shall be designed in such a way that the requirements for summer heat insulation specified in Annex 2 point 4 are met.

Table 2.30 – Design of the reference building [26].

Line	Component	Property	Technical reference design (unit)

		(concerning lines 1.1 to 1.13)	For zones with interior temperatures ≥ 19 °C when heated	For zones with interior temperatures < 19 °C when heated
1.0	The annual primary energy requirement of the reference building according to lines 1.1 to 8, calculated according to one of the methods specified in Annex 2 (2) or (3), shall be multiplied by a factor of 0.75 for new construction projects from 1 January 2016.			
1.1	External wall (including internals, such as roller shutter box), floors against outside air	Heat transfer coefficient	U = 0.28 W/(m²·K)	U = 0.35 W/(m²·K)
1.2	Curtain walls	Heat transfer coefficient	U = 1.4 W/(m²·K)	U = 1.9 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.48	g⊥ = 0.60
		Light transmission of the glazing	t_{D65} = 0.72	t_{D65} = 0.78
1.3	Walls against the ground, floor slab, walls and ceilings to unheated rooms (except side walls according to line 1.4)	Heat transfer coefficient	U = 0.35 W/(m²·K)	U = 0.35 W/(m²·K)
1.4	Roof (if not according to 1.5), top floor, side walls	Heat transfer coefficient	U = 0.20 W/(m²·K)	U = 0.35 W/(m²·K)
1.5	Glass roofs	Heat transfer coefficient	U_W = 2.7 W/(m²·K)	U_W = 2.7 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.63	g⊥ = 0.,63
		Light transmission of the glazing	t_{D65} = 0.76	t_{D65} = 0.76
1.6	Roof lights	Heat transfer coefficient	U_W = 2.4 W/(m²·K)	U_W = 2.4 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.55	g⊥ = 0.55
		Light transmission of the glazing	t_{D65} = 0.48	t_{D65} = 0.48
1.7	Skylights	Heat transfer coefficient	U_W = 2.7 W/(m²·K)	U_W = 2.7 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.64	g⊥ = 0.64
		Light transmission of the glazing	t_{D65} = 0.59	t_{D65} = 0.59
1.8	Windows & French doors (see also Line 1.14)	Heat transfer coefficient	U_W = 1.3 W/(m²·K)	U_W = 1.9 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.60	g⊥ = 0.60
		Light transmission of the glazing	t_{D65} = 0.78	t_{D65} = 0.78

1.9	Roof windows (see also Line 1.14)	Heat transfer coefficient	U_W = 1.4 W/(m²·K)	U_W = 1.9 W/(m²·K)
		Total energy transmittance of the glazing	g⊥ = 0.60	g⊥ = 0.60
		Light transmission of the glazing	t_{D65} = 0.78	t_{D65} = 0.78
[...]	*Not related*			
1.13	Daylight supply (when sun or glare protection)	Daylight supply factor $C_{TL,Vers,SA}$ acc. to DIN V 18599-4: 2011-12	• no sun or glare protection available: 0.70 • glare protection available: 0.15	
1.14	Sun protection device	For the reference building, the actual sun protection device of the building to be constructed shall be assumed; it may result from the requirements for summer heat protection according to number 4 or from the requirements of glare protection. Insofar as sun protection glazing is used for this purpose, the following parameters shall be used for this glazing: • Instead of the values of line 1.2: - Total energy transmittance of glazing g⊥ = 0.35 - Light transmission of the glazing t_{D65} = 0.58 • Instead of the values in lines 1.8 and 1.9: - Total energy transmittance of glazing g⊥ = 0.35 - Light transmission of the glazing t_{D65} = 0.62		

Table 2.31 - Maximum U-values for non-residential buildings for new construction projects from 1st of January 2016 [26].

Line	Component	Mean U-value (W/(m²·K)) according to the second amendment of EnEV 2013	
		Zones with interior temperatures ≥ 19 °C when heated	Zones with interior temperatures from 12 to < 19 °C when heated
1	Opaque exterior components, unless included in rows 3 and 4	0.28	0.50
2	Transparent exterior components, unless included in rows 3 and 4	1.5	2.8
3	Curtain wall	1.5	3.0
4	Glass roofs, skylights	2.5	3.1

If only individual components are replaced, such as the glazing in existing buildings, other specifications apply. Those are described in section 3, § 9 of the EnEV. Insofar as changes are made in the heated or cooled rooms of buildings (as described below), the changes shall be such that the heat transfer coefficients of the affected areas do not exceed the maximum values of the heat transfer coefficients specified for such external components. The requirements of sentence 1 are considered fulfilled if changed non-residential buildings in total do not exceed the annual primary energy demand of the reference building according to section 2, § 4 (1) and the maximum values of the mean heat transfer coefficients of the heat-transferring enclosure according to Table 2.31 lines 1, 2, 3 and 4 by more than 40%. If energetic characteristic values for existing components and system components are not available, reliable empirical values for components and system components of comparable age groups can be used.

The Annex 3 of EnEV regulation describes the requirements for the modification of exterior components and for construction of small buildings. In heated or refrigerated rooms against outside air delimiting windows, French doors, skylights and glass roofs are renewed in such a way that:

a. The entire component is replaced or installed for the first time,
b. Additional front or interior windows are installed or
c. The glazing or glazed sashes are replaced.

It must be complied with the requirements of Table 2.32, line 2. If measures according to (a) are made on French doors with folding, sliding or lifting mechanisms, the requirements according to Table 2.32 line 2f must be observed. For measures referred to in point (c), sentence 1 of the regulation shall not apply if the existing frame is unsuitable for receiving the prescribed glazing. If measures are taken in accordance with point (c) and the thickness of the glass is limited for technical reasons, the requirements shall be considered to be fulfilled if glazing with a heat transfer coefficient not exceeding 1.3 W/(m^2·K) is installed. Where measures under (c) are applied to box or composite windows, the requirements shall be deemed to be met if a glass sheet with an infrared reflecting coating with an emissivity $\varepsilon_n \leq 0.2$ is installed.
Insofar as curtain walls, the design of which corresponds to DIN EN 13947: 2007-07, are renewed in heated or cooled rooms in such a way that the entire component is replaced or installed for the first time, the requirements according to Table 2.32 Line 2d must be observed. If special glazing in accordance with section 2 sentence 5 is used for measures pursuant to sentence 1, the requirements according to Table 2.32 line 3c must be observed, notwithstanding sentence 1.

Table 2.32 – Maximum U-values when installing, replacing and renewing components for the first time [26].

Line	Component	Maximum U-value (W/(m^2·K)) [a]	
		Residential buildings and zones of non-residential buildings with internal temperatures ≥ 19 °C	Zones of non-residential buildings with internal temperatures from 12 to < 19 °C
1	Exterior walls	0.24	0.35
2a	Windows, French doors	1.3	1.9
2b	Roof windows	1.4	1.9
2c	Glazing	1.1	No requirement
2d	Curtain walls	1.5 [b]	1.9 [b]
2e	Glass roofs	2.0	2.7
2f	French doors with folding mechanism, sliding mechanism or lifting mechanism	1.6	1.9
3a	Windows, French doors, roof windows with special glazing	2.0	2.8
3b	Special glazing	1.6	No requirement
3c	Curtain walls with special glazing	2.3 [b]	3.0 [b]
4a	Roof areas including skylights, walls against unheated roof space (including side walls), top floors	0.24	0.35

4b	Roof areas with insulation	0.20	0.35
5a	Walls against the ground or unheated rooms (with the exception of attics)	0.30	No requirement
5b	Floors	0.50	No requirement

[a] Thermal transmittance of the component taking into account the new and existing component layers: DIN V 4108-6: 2003-06, Annex E is used for the calculation of the components according to lines 5a and b and DIN EN ISO 6946: 2008-04 is used for the calculation of other opaque components

[b] The thermal transmittance of the curtain wall is to be determined according to DIN EN 13947: 2007-07

Concerning the format and content of the Energy Performance Certificates (EPCs), the German legislation does not discern between public and large buildings visited by the public and other non-residential buildings. Figure 2.24 presents an example of a filled EPC in Germany.

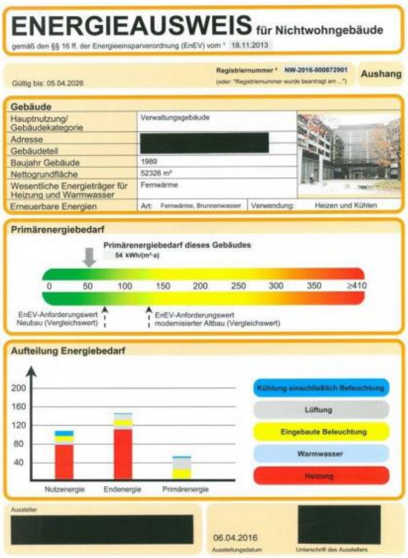

Figure 2.24 - Example of a filled-in Energy Performance Certificate in Germany [27].

2.5.3. Greece

The transposition of the European Directive on the energy performance of buildings (EPBD) in Greece was enacted in 2008 by a national law. The Greek Regulation for the Energy Efficiency of Buildings (KENAK) [28] was released in 2010 and revised in 2017. This national regulation outlines the overall approach for the energy performance of the building sector in accordance to European standards and EPBD mandates.

According to KENAK, Greece is divided in four climatic zones, as illustrated in Figure 2.25. Athens belongs in climatic zone B.

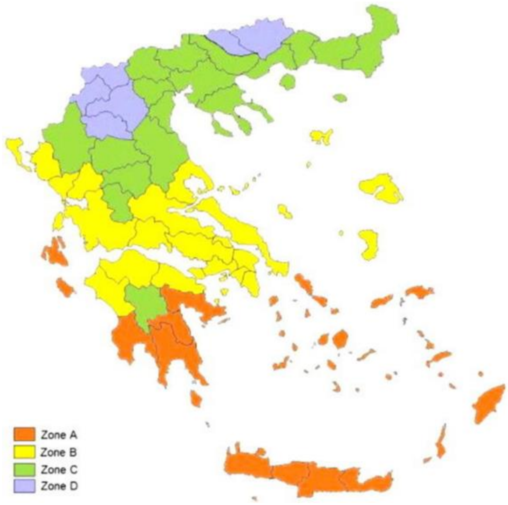

Figure 2.25 – Climatic zones in Greece.

Article 8 of the Greek Regulation for the Energy Efficiency of Buildings (KENAK) defines the maximum acceptable U-values for the different components of a building, without any distinction between the residential and non-residential buildings. For new buildings these values are presented in Table 2.33 for the four different climatic zones in Greece. In the case of a deep renovation of an existing building, the maximum acceptable U-values are described in Table 2.34. The standard regarding the energy saving for new non-residential buildings is the ISO 13790:2008 [29] and now revised by ISO 52016-1:2017 [30].

Table 2.33 - Maximum acceptable U-values for building components for the four Greek climatic zones in the case of a new building [28].

Building component	Maximum acceptable U-value (W/(m²·K))			
	Zone A	Zone B	Zone C	Zone D
External horizontal or tilted surface in contact with the external air (roof)	0.45	0.40	0.35	0.30
External wall in contact with the external air	0.55	0.45	0.40	0.35
Floor in contact with external air	0.45	0.40	0.35	0.30
Horizontal or tilted roof in contact with a closed unheated space	1.10	0.80	0.65	0.60
Wall in contact with a closed unheated space	1.30	0.90	0.70	0.65
Floor in contact with a closed unheated space	1.10	0.80	0.65	0.60
Horizontal or tilted roof in contact with the ground	1.10	0.80	0.65	0.60
Wall in contact with the ground	1.30	0.90	0.70	0.65
Floor in contact with the ground	1.10	0.80	0.65	0.60
Fixed or partly operable glass facade in contact with the external air	**2.10**	**1.90**	**1.75**	**1.70**

Table 2.34 - Maximum acceptable U-values for building components for the four Greek climatic zones in the case of a deep renovation of an existing building [28].

Building component	Maximum acceptable U-value (W/(m²·K))			
	Zone A	Zone B	Zone C	Zone D
External horizontal or tilted surface in contact with the external air (roof)	0.50	0.45	0.40	0.35
External wall in contact with the external air	0.60	0.50	0.45	0.40
Floor in contact with external air	0.50	0.45	0.40	0.35
Horizontal or tilted roof in contact with a closed unheated space	1.20	0.90	0.75	0.70

Wall in contact with a closed unheated space	1.50	1.00	0.80	0.70
Floor in contact with a closed unheated space	1.20	0.90	0.75	0.70
Horizontal or tilted roof in contact with the ground	1.20	0.90	0.75	0.70
Wall in contact with the ground	1.50	1.00	0.80	0.70
Floor in contact with the ground	1.20	0.90	0.75	0.70
Fixed or partly operable glass facade in contact with the external air	**2.20**	**2.00**	**1.80**	**1.80**

Table 2.35 – The main U-value requirement for EPB new building

Element	U-value (W/(m²K))
Roof	0.24
External walls	0.24
Ground floor	0.30
Windows (U_w)	1.8
Curtain walls (U_{cw})	2.0
Glass (U_g)	1.1

According to directives of the European Union, the Greek government was obliged to introduce new legislation, regarding energy efficiency of buildings. As a result of that, the procedure of building energy efficiency inspection was enacted, which includes the assessment of major building features. The final results of these calculations are depicted on the EPC document making an assessment of the amount of energy a building consumes, which is then rated on a nine-grade scale from A+ to H, A+ being the highest and most efficient. The minimum acceptable class for new buildings and for those undergoing major renovations is ‘B’.

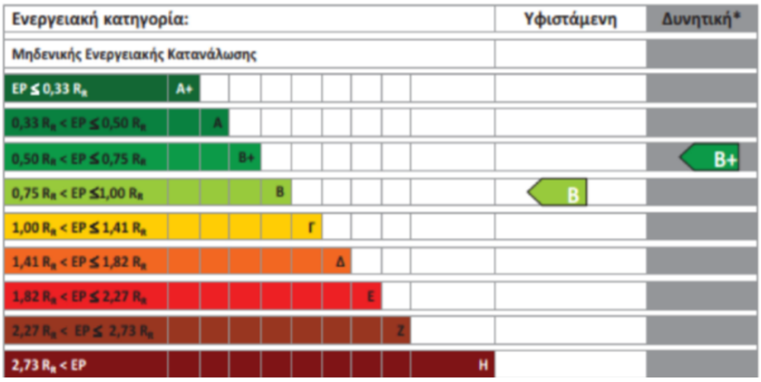

Figure 2.26 - Classification of Greek buildings according to their Energy Performance (EP)

For non-residential nearly Zero-Energy Buildings (nZEBs) the following limits have been selected:

- For new tertiary sector buildings, a maximum use of primary energy of 85 kWh/(m²·y), with 20 % renewable energy minimum.
- For existing tertiary sector buildings, a maximum use of primary energy of 90 kWh/(m²·y), with 15 % renewable energy minimum.

2.5.4. Sweden

Sweden is divided in four climatic zones, as depicted in Figure 2.27. The new climatic zone IV includes municipalities in southern and western Sweden. The new zone tightened requirements by about 10% compared to the new levels that were adjusted for climatic zone III [31]. Stockholm and Uppsala belong in the climate zone III.

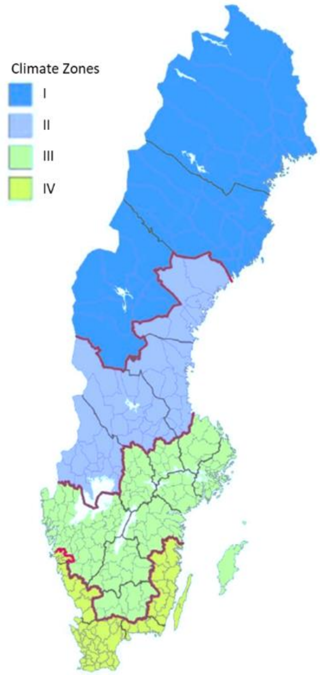

Figure 2.27 - Swedish climatic zones I-IV from north to south [31].

From July 2017, all new building permits should comply with the nearly Zero-Energy Building (nZEB) standard, implying that the nZEB definition equals to the current building code. The requirements are the same for existing buildings undergoing renovation, but then adjusted depending on the size of the renovation measures. The government is planning to tighten the building code again in 2021.

The average heat transfer coefficient for building components and thermal bridges (W/m^{2}K) is determined in accordance with SS-EN ISO 13789:2007 and SS 24230 according to the following equation:

$$U_m = \frac{\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \Psi_k + \sum_{j=1}^{p} X_j}{A_{om}} \qquad \text{2-19}$$

where:

- U_i is the heat transfer coefficient for building component i (W/(m^{2}K)).
- A_i is the area of the building component i's surface against heated parts of dwellings or premises. For windows, doors, gates and the like, A_i is calculated with the outer frame dimension. The building's entire indoor height is used in the calculations, i.e. from the upper edge of the lower joists to the lower edge of the attic joists.
- Ψ_k is the heat transfer coefficient for the linear thermal bridge k (W/(mK)).
- l_k is the length of the linear thermal bridge k (m).
- X_j is the heat transfer coefficient for the point thermal bridge j (W/K).
- A_{om} is the total area of enclosed building components' surfaces against heated parts of dwellings or premises. Enclosed building components refer to such building components that border on heated parts of dwellings or premises towards the outside, towards the ground or towards partially heated spaces.

The average thermal transmittance (U_m) of the building envelope (A_{om}) should be equal to 0.6 W/(m^2·K), both electrically and non-electrically heated non-residential building [32].

The building's energy performance is expressed by the building's primary energy number (EP_{pet}), which is comprised of the building's energy use, where energy for space heating has been corrected with a geographical adjustment factor (F_{geo}), multiplied by a primary energy factor for energy carriers (PE_i) and distributed on A_{temp} (kWh/m^2 per year). The primary energy number (EP_{pet}) is calculated according to the following equation:

$$EP_{pet} = \frac{\sum_{i=1}^{6}\left(\frac{E_{uppv,i}}{F_{geo}} + E_{kyl,i} + E_{tvv,i} + E_{f,i}\right)\cdot PE_i}{A_{temp}} \quad 2\text{-}20$$

Where:

- E_{uppv} is the energy for space heating (kWh/year).
- E_{kyl} is the energy for air conditioning (kWh/year).
- E_{tvv} is the energy hot tap water (kWh/year).
- E_f is the building's property energy (kWh/year). The property energy is the part of the building's energy use that is related to the building's needs where the energy-intensive device is within, below or placed on the outside of the building. Property energy includes fixed lighting in public spaces and operating spaces. Energy used in heating cables, pumps, fans, engines, control and monitoring equipment and the like is also included. Externally locally placed devices that supply the building, such as pumps and fans for free cooling, are included. Devices intended for other use than for the building, such as engine and cab heaters for vehicles, battery chargers for external users, lighting in the garden and on walkways, are not included. Property electricity refers to the part of the property energy that is electricity-based.

Table 2.36 – Energy use requirements for new non-residential buildings with and without electrical heating, climate zone III [31].

	2006	2009	2012	2015	PE-ratio	2017
Electrically heated [kWhr/m²][a,b]	100[c]	55[e]	55[e]	50[e]	70/50 =1.40	NZEB planned for all buildings July 2017
Non-electrically heated [kWhr/m²]		100[d]	80[d]	70[d]		

[a] Electrically heated defined as more than 10 W/m² installed power
[b] Electrical heating devices should comply with a maximum power limit
Addendum if the $q_{hygiene}$ is between 0.35 and 1.0 l/s, m_2
[c] Addendum if the $q_{hygiene}$ is between 0.35 and 1.0 l/s, m_2+110*(q-0.35) [kWh/m²]
[d] Addendum if the $q_{hygiene}$ is between 0.35 and 1.0 l/s, m_2+70*(q-0.35) [kWh/m²]
[e] Addendum if the $q_{hygiene}$ is between 0.35 and 1.0 l/s, m_2+45*(q-0.35) [kWh/m²]

If the building does not meet the requirements for the primary energy number, the U-values presented in the Table 2.37 shall be pursued in changes to the building envelope:

Table 2.37 – U-values of the envelope elements in the case where the building does not meet the primary energy requirements

Part of the building envelope	U_i (W/(m²·K))
Roof	0.13
Wall	0.18
Floor	0.15
Window	1.2
Exterior door	1.2

Energy consumption is described in the energy performance certificate in terms of energy performance measures. Energy performance measures indicate how much energy is consumed by heating, air-conditioning, hot tap water and the building's property electricity.

Energy classification is included in the certificates to enable comparison of the building energy consumption. Energy Class A stands for low energy consumption, and G stands for high. A building that has an energy consumption corresponding to the requirement imposed on a newly built building today is placed in Class C. The seven classes on the scale are based on the energy consumption requirement imposed on new buildings built today. These requirements can be found in the building code, BBR (BFS 2011:6) and depend on the type of building, if it is electrically heated or not, and where in Sweden it is situated.

Below is a list showing what each energy class stands for:

- Class A: EP ≤ 50 percent of the requirement for a new building.
- Class B: 50 < EP ≤ 75 percent of the requirement for a new building.
- Class C: 75 < EP ≤ 100 percent of the requirement for a new building.
- Class D: 100 < EP ≤ 135 percent of the requirement for a new building.
- Class E: 135 < EP ≤ 180 percent of the requirement for a new building.
- Class F: 180 < EP ≤ 235 percent of the requirement for a new building.
- Class G: EP > 235 percent of the requirement for a new building.

2.6. General specifications and regulations for windows

Table 2.38 summarises the international and European standards regarding innovative glazing systems, such as laminated, insulated, soda lime silicate and electrochromic glazing systems.

Table 2.38 – International standards for building glass.

Number	Title	Issue date	Content
ISO 12543-4	Glass in building - Laminated glass and laminated safety glass – Part 4: Test methods for durability	2011-12	Describes UV irradiation test for laminated and laminated safety glass (2000 h @ 45°C), heat soak (16 h @ 100°C) and wet storage (2 weeks 50°C @ 80% rH)
ISO 1279-2	Glass in building - Insulating glass units - Part 2: Long term test method and requirements for moisture penetration	2018-10	Describes climate change test for a double glazed unit (-18°C to +53°C in turn for 4 weeks, +58°C @ 95% rH for 7 weeks)
EN 1863-1	Glass in building - Heat strengthened soda lime silicate glass - Part 1: Definition and description;	2012-02	Describes appearance and test for partly toughened glass (TVG)
EN 1863-2	Glass in building - Heat strengthened soda lime silicate glass - Part 2: Evaluation of conformity/ Product standard	2005-01	
EN 12150-2	Glass in building - Thermally toughened soda lime silicate safety glass - Part 2: Product standard	2017-12	Describes appearance and test for toughened glass (ESG)
ISO 14179-2	Glass in building - Heat soaked thermally toughened soda lime silicate safety glass - Part 2: Product standard	2017-12	Describes appearance and test for hot soaked toughened glass (ESG-H)
ISO 14449	Glass in building - Laminated glass and laminated safety glass - Product standard	2017-12	Describes the conformity assessment and the procedure for CE marking for a laminated glass.
ISO 20492	Glass in buildings - Insulating glass - Part 1: Durability of edge seals by climate tests	2008-10	Describes the durability tests of insulating glass
ISO 18543	Glass in building - Electrochromic glazing - Accelerated ageing test and requirements	2017-10	Describes the testing scenario for electrochromic switchable glass (5000 h @ 85°C @ 850 W/sqm UV

			and 50.000 switching cycles); based upon American standard ASTM 2141.

The general standards used in European countries to determine the most important thermal and optical properties of windows are summarized in the Table 2.39.

Table 2.39: Standards used for the calculation of thermal and optical properties of windows

Standard	Title
EN 673	Glass in building-Determination of thermal transmittance (U-value) - Calculation method
ISO 10077-1	Thermal performance of windows, doors and shutters-Calculation of thermal transmittance - Part 1: General
ISO 10077-2	Thermal performance of windows, doors and shutters-Calculation of thermal transmittance - Part 2: Numerical method for frames
EN 410	Glass in building-Determination of luminous and solar characteristics of glazing
EN 1026	Windows and doors – Air permeability – Test method
EN 12207	Windows and doors – Air permeability – Classification

2.6.1. Glazing thermal transmittance

The European Standard EN 673 specifies a calculation method to determine the thermal transmittance (U-value) in the central area of glazing with flat and parallel surfaces [33]. It can be applied to uncoated glass, coated glass and materials not transparent in the far infrared. It applies also to multiple glazing comprising such glasses and/or materials. It does not apply to multiple glazing which includes in the gas space sheets or foils that are far infrared transparent. For the purpose of product comparison, a vertical position of the glazing is specified.

Table 2.40: Glazing thermal transmittance calculation procedure according to EN 673 [33].

Calculated value	Equation	Nomenclature
Thermal transmittance of the glazing U_g	$\frac{1}{U_g} = \frac{1}{h_e} + \frac{1}{h_t} + \frac{1}{h_i}$	h_e = external heat transfer coefficient, with a standarised value of 25 W/(m^2·K) for ordinary vertical glass h_i = internal heat transfer coefficient h_t = total thermal conductance of the glazing
Total thermal conductance of the glazing h_t	$\frac{1}{h_t} = \sum_1^N \frac{1}{h_s} + \sum_1^M d_j \cdot r_j$	N = the number of gas spaces h_s = the thermal conductance of each gas space M = the number of material layers d_j = the thickness of material layer j r_j = the thermal resistivity of material layer j
Thermal conductance of the k^{th} gas space $h_{s,k}$	$h_{s,k} = h_{r,k} + h_{g,k}$	$h_{r,k}$ = the radiation conductance of the k^{th} space, calculated according to section 5.3 of the standard $h_{g,k}$ = the U value of the gas in the k^{th} space, calculated according to section 5.4 of the standard **NOTE 1:** For gas mixtures, the gas properties needed for the calculation are proportioned in the ratio of the volume fractions, according to Equation (9) of the standard **NOTE 2**: For glazing with more than one gas space (N>1) an iteration procedure, described in Annex A of the standard, is needed for the calculation of h_s

Internal heat transfer coefficient h_i	$h_i = h_r + h_c$	h_r = the internal radiative heat transfer coefficient, calculated according to section 7.2 of the standard h_c = the internal convective heat transfer coefficient, equal to 3.6 $W/(m^2 \cdot K)$ for free convection

For gases that absorb infrared radiation in the (5-50) µm range which are used in combination with a coating with corrected emissivity greater or equal to 0.2, the U value shall be measured according to EN 674 or EN 675, as explained in section 6.3 of the standard. The corrected emissivity, where needed, is determined in accordance with EN 12898.

2.6.2. Frame and linear thermal transmittance

ISO 10077-2 specifies a method and gives reference input data for the calculation of the thermal transmittance of frame profiles and of the linear thermal transmittance of their junction with glazing or opaque panels [34].

Table 2.41: Frame and linear thermal transmittance calculation procedure according to ISO 10077-2 [34]

Calculated value	Equation
Thermal transmittance of the frame section U_f	$$U_f = \frac{L_f^{2D} - U_p \cdot b_p}{b_f}$$ L_f^{2D} = the two-dimensional thermal conductance (see ISO 10211) U_p = the thermal transmittance of the central area of the panel b_f = the larger of the projected widths of the frame section (without protruding gaskets), as seen from both sides b_p = the visible width of the panel, measured on the same side as b_f
Linear thermal transmittance Ψ_g	$$\Psi_g = L_\Psi^{2D} - U_f \cdot b_f - U_g \cdot b_g$$ L_Ψ^{2D} = the two-dimensional thermal conductance (see ISO 10211) U_g = the thermal transmittance of the central area of the glazing b_g = the visible width of the glazing, measured on the same side as b_f

2.6.3. Whole window thermal transmittance

ISO 10077-1 specifies methods for the calculation of the thermal transmittance of windows and pedestrian doors consisting of glazed and/or or opaque panels fitted in a frame, with and without shutters.

Table 2.42: Thermal transmittance calculation procedure according to ISO 10077-1 [35].

Calculated value	Equation
Thermal transmittance of a single window U_w	$$U_w = \frac{\sum A_g U_g + \sum A_f U_f + \sum l_g \Psi_g}{\sum A_g + \sum A_f}$$ A_g = the glazed area (the smaller of the visible areas seen from both sides) A_f = the frame area (the larger of the two projected areas seen from both sides) l_g = the total perimeter of the glazing, equal to the sum of the visible perimeter of the glass panes in the window. If the perimeters are different on either side of the pane, then the larger of the two shall be used Ψ_g = the linear thermal transmittance due to combined thermal effects of glazing, spacer and frame. For single glazing it is considered equal to zero (no spacer effect) **NOTE 1:** The summations included in Equation are used to allow for different parts of the glazing or frame, e.g. several values of A_f are needed when different values of U_f apply to the sill, head, jambs and dividers.
Thermal transmittance of a double window U_w	$$U_w = \frac{1}{\frac{1}{U_{w1}} - R_{si} + R_s - R_{se} + \frac{1}{U_{w2}}}$$

	U_{w1}, U_{w2} = the thermal transmittances of the external and internal window, respectively, calculated according to Equation R_{si} = the internal surface resistance of the external window when used alone R_{se} = the external surface resistance of the internal window when used alone R_s = the thermal resistance of the space between the glazing in the two windows **NOTE:** Typical values of R_{si} and R_{se} are given in the standard.

2.6.4. Glazing luminous and solar characteristics

The European Standard EN 410 specifies methods of determining the luminous and solar characteristics of glazing in buildings. It applies both to conventional glazing and to absorbing or reflecting solar-control glazing, used as vertical or horizontal glazed apertures. The appropriate formulae for single, double and triple glazing are given.

This European Standard is accordingly applicable to all transparent materials except those which show significant transmission in the wavelength region 5 µm to 50 µm of ambient temperature radiation, such as certain plastic materials. Angular light and solar properties of glass in building are excluded from this standard. To characterize glazing, the principal parameters are its visible transmittance (τ_{vis}) and solar factor (g).

Table 2.43: Glazing visible transmittance and solar factor calculation procedure according to EN 410 [36].

Calculated value	Equation
Glazing visible transmittance τ_{vis}	$$\tau_{vis} = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda}$$ Dλ = the relative spectral distribution of illuminant D65 [Dλ·V(λ) values are indicated in Table 1 of the standard for wavelength intervals of 10 nm] τ(λ) = the spectral transmittance of the glazing V(λ) = the spectral luminous efficiency for photopic vision defining the standard observer for photometry Δλ = the wavelength interval
Triple glazing spectral transmittance τ(λ)	$$\tau(\lambda) = \frac{\tau_1(\lambda)\tau_2(\lambda)\tau_3(\lambda)}{[1-\rho'_1(\lambda)\rho_2(\lambda)][1-\rho'_2(\lambda)\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\rho_3(\lambda)}$$ $\tau_1(\lambda)$ = the spectral transmittance of the first (outer) pane $\tau_2(\lambda)$ = the spectral transmittance of the second pane $\tau_3(\lambda)$ = the spectral transmittance of the third (inner) pane $\rho'_1(\lambda)$ = the spectral reflectance of the first (outer) pane, measured in the direction opposite to the incident radiation $\rho_2(\lambda)$ = the spectral reflectance of the second pane, measured in the direction of the incident radiation $\rho'_2(\lambda)$ = the spectral reflectance of the second pane, measured in the direction opposite to the incident radiation $\rho_3(\lambda)$ = the spectral reflectance of the third (inner) pane, measured in the direction of the incident radiation
Total solar energy transmittance / solar factor, g-value	$$g = \tau_e + q_i$$ τ_e = the solar direct transmittance q_i = the secondary heat transfer factor of the glazing towards the inside
Solar direct transmittance τ_e	$$\tau_e = \frac{\sum_{\lambda=300\text{ nm}}^{2500\text{ nm}} S_\lambda \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2500\text{ nm}} S_\lambda \cdot \Delta\lambda}$$ S_λ = the relative spectral distribution of the solar radiation [$S_\lambda \cdot \Delta\lambda$ values are indicated in Table 2 of the standard]

Secondary heat transfer factor of the glazing towards the inside q_i	$$q_i = \frac{\left[\frac{\alpha_{e3}}{\Lambda_{23}} + \frac{\alpha_{e3}+\alpha_{e2}}{\Lambda_{12}} + \frac{\alpha_{e3}+\alpha_{e2}+\alpha_{e1}}{h_e}\right]}{\frac{1}{h_i}+\frac{1}{h_e}+\frac{1}{\Lambda_{12}}+\frac{1}{\Lambda_{23}}}$$ α_{ek} = the solar direct absorptance of the kth pane within the triple glazing (calculated according to section 5.4.6.4 of the standard) h_e = the heat transfer coefficient towards the outside, with a standard value of 25 W/(m^2·K) h_i = the heat transfer coefficient towards the inside Λ_{12} = the thermal conductance between the outer surface of the first pane and the centre of the second pane Λ_{23} = the thermal conductance between the centre of the second pane and the innermost surface of the third pane **NOTE:** The thermal conductance Λ is calculated according to EN 673 whenever possible or measured according to EN 674 or EN 675.
Heat transfer coefficient towards the inside h_i	$$h_i = 3.6 + \frac{4.1 \cdot \varepsilon_i}{0.837}$$ ε_i = the corrected emissivity of the inside surface (defined according to EN 12898)

Annex B of the EN 410 standard can be used for the calculation of the spectral characteristics of laminated glass. The EN 410 standard can also be used to calculate the general colour rendering index Ra, which expresses the colour rendering properties of glazing in transmission, according to the procedure describing in the Table 2.44.

Table 2.44: Glazing general colour rendering index calculation procedure according to EN 410 [36].

Calculated value	Equation
General colour rendering index R_a	$$R_a = \sum_{i=1}^{8} R_i$$ R_i = the specific colour rendering index for each test colour i=1,2,…,8
Specific colour rendering index of the ith colour R_i	$$R_i = 100 - 4.6 \cdot \Delta E_i$$ ΔE_i = the total distortion of each test colour i=1,2,…,8
Total distortion of the ith colour ΔE_i	$$\Delta E_i = \sqrt{\left(U^*_{t,i} - U^*_{r,i}\right)^2 + \left(V^*_{t,i} - V^*_{r,i}\right)^2 + \left(W^*_{t,i} - W^*_{r,i}\right)^2}$$ The values of $U^*_{r,i}$, $V^*_{r,i}$, $W^*_{r,i}$ are calculated for the test colours, lighted by the standard illuminant D65 without the glazing being interposed and are given in Table 7 of the standard The values of $U^*_{t,i}$, $V^*_{t,i}$, $W^*_{t,i}$ are calculated according to section 5.6 of the standard

The general colour rendering index may attain a maximum value of 100. This will be achieved for glazing whose spectral transmittance is completely constant in the visible spectral range. In the technique of illumination, general colour rendering indices R_a>90 characterize a very good and values R_a>80 a good colour rendering.

2.6.5. Air permeability and classification

The European Standard EN 1026 defines the test method to be used to determine the air permeability of completely assembled windows of any material, when submitted to positive or negative test pressures [37]. This test method is designed to take account of conditions in use, when the window is installed in accordance with the manufacturer's specification and the requirements of relevant European Standards and codes of practice.

A chamber with an open side to which the test specimen can be fitted is used for the test. The test is based on the application of three pressure pulses, each 10 % greater than the maximum test pressure to be used in the test or 500 Pa, whichever is greater. The time to reach the maximum test pressure shall be not less than 1 s and the pressure shall be sustained for at least 3 s. Air permeability is measured and recorded at each step. The duration of each step shall be sufficient to allow the test pressure to stabilise before the air permeability is measured.

The results of the air flow measurements (V_x) are adjusted at each step to calculate the air flow (V_o) at normal conditions (T_o=293 K, P_o=101.3 kPa), considering the actual temperature T_x (in °C) and atmospheric pressure P_x (in kPa) during the test:

$$V_o = V_x \cdot \frac{293}{273 + T_x} \cdot \frac{P_x}{101.3} \quad \text{2-21}$$

For a specimen, the air permeability at each step is equal to the overall air permeability adjusted in accordance with Equation 2-21 less the air permeability of the chamber, when not zero, adjusted in accordance with Equation 2-21. Using the length of the opening joint and the overall area, the air permeability is calculated in terms of $m^3/(h\cdot m)$ and $m^3/(h\cdot m^2)$, expressing the results to two significant figures. The air permeability (V_o) related to the length of joint (V_L) and the overall area (VA) are recorded on a graph for each pressure step [37].

The European Standard EN 12207 is used for the classification of windows in terms of air permeability. The classification is based on a comparison of the air permeability of the test specimen related to overall area and on the air permeability related to the length of opening joint. The reference air permeabilities for overall area and joint length are defined at a reference test pressure of 100 Pa. For other pressure steps, the following equation is used:

$$Q = Q_{100} \cdot \left(\frac{P}{100}\right)^{2/3} \quad \text{2-22}$$

where Q_{100} is the reference air permeability at a test pressure of 100 Pa and Q is the air permeability at a test pressure P.

The lines defining the upper limits of each class are derived from the reference air permeabilities at 100 Pa related to overall area length of opening joint, see Table 2.45 and Table 2.46. A specimen belongs to a specified class if the measured air permeability does not exceed the upper limit at any test pressure step in that class.

Table 2.45: Reference air permeabilities at 100 Pa and maximum test pressures, related to overall area, for classes 1 to 4 [38].

Class	Reference air permeability at 100 Pa ($m^3/(m^2\cdot h)$)	Maximum test pressure (Pa)
0	Not tested	
1	50	150
2	27	300
3	9	600
4	3	600

Table 2.46: Reference air permeabilities at 100 Pa and maximum test pressures, related to joints length, for classes 1 to 4 [38]

Class	Reference air permeability at 100 Pa ($m^3/(m^2\cdot h)$)	Maximum test pressure (Pa)
0	Not tested	
1	12.50	150
2	6.75	300
3	2.25	600
4	0.75	600

If a specimen is classified according to the overall area and the length of the opening joint, which give:

- The same class, then the specimen shall be classified in one and the same class
- Two adjacent classes, then the specimen shall be classified in the most favourable class (with lower rate)

- A difference of two classes, then the specimen shall be classified in the mean class
- A difference of more than two classes, then the specimen shall not be classified.

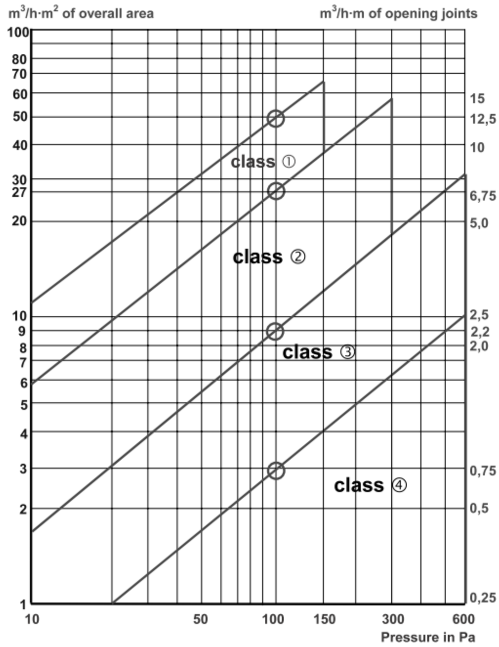

Figure 2.28 – Classification of specimen according to overall area and opening [38].

2.6.6. General specifications and regulations for windows in target countries

The national regulations regarding windows and glazing of the target countries, Belgium, Germany, Greece and Sweden, uses the European standards EN 410:2011 [36] and EN 12464 [18, 19] as approved best practice tool reference. Moreover, for adaptive glazing, the reference standard that is used by countries is the ISO 9050: 2003 [39] and the EN 17037 [40], focusing on quantity and quality of daylight for building users.

2.7. Fire-safety requirements

Construction products and building elements have different reaction and resistance to fire.

2.7.1. Reaction to fire

EN 13501-1 defines the procedure for the classification of reaction to fire of construction products [41]. This classification is based on specific test procedures and all products, including products incorporated within building elements, are considered in relation to their end use application. Performance levels for each specific parameter are determined from the test methods. Table 2.47 summarizes the determined parameters.

Table 2.47 - Parameters determined regarding performance of reaction to fire

Parameter	Description
ΔT	temperature rise [K]
Δm	mass loss [%]
t_f	duration of sustained flaming [s]
PCS	gross calorific potential [MJ/kg or MJ/m^2]
PCI	net calorific potential [MJ/kg or MJ/m^2]
FIGRA 0,2MJ	fire growth rate index at THR threshold of 0,2 MJ
FIGRA 0,4MJ	fire growth rate index at THR threshold of 0,4 MJ
THR 600s	total heat release within 600 s [MJ]
SMOGRA	smoke growth rate [m^2/s^2]

TSP 600s	total smoke production within 600 s [m²]
F_s	flame spread [mm]
LFS	lateral flame spread [m]

Table 2.48 gives the classes of reaction to fire with their corresponding fire performance, for construction products excluding floorings, according to EN 13501-1 [41].

Table 2.48 - Classes of reaction to fire performance for construction products excluding floorings and linear pipe thermal insulation products [41]

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182	$\Delta T \leq 30$ °C; and $\Delta m \leq 50$ %; and t_f=0(i.e.no sustained flaming)	-
	EN ISO 1716	PCS ≤ 2,0 MJ/kg and PCS ≤ 1,4 MJ/m²	-
A2	EN ISO 1182	$\Delta T \leq 50$ °C; and $\Delta m \leq 50$ %; and $t_f \leq 20$s	-
	EN ISO 1716	PCS ≤ 3,0 MJ/kg and PCS ≤ 4,0 MJ/m²	-
	EN 13823	FIGRA ≤ 120 W/s and LFS<edge of specimen and THR 600s ≤ 7,5 MJ	Smoke production and Flaming droplets/particles
B	EN 13823	FIGRA ≤ 120 W/s and LFS<edge of specimen and THR 600s ≤ 7,5 MJ	Smoke production and Flaming droplets/particles
	EN ISO 11925-2: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
C	EN 13823	FIGRA ≤ 250 W/s and LFS<edge of specimen and THR 600s ≤ 15 MJ	Smoke production and Flaming droplets/particles
	EN ISO 11925-2: Exposure = 30 s	$F_s \leq 150$mm within 60 s	
D	EN 13823	FIGRA ≤ 750 W/s	Smoke production and Flaming droplets/particles
	EN ISO 11925-2: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
E	EN ISO 11925-2: Exposure = 15 s	$F_s \leq 150$ mm within 20 s	Flaming droplets/particles
F	No performance determined		

Products classified in a given class are deemed to satisfy all the requirements of any lower class. Products classified A2, B, C, D obtain an additional classification of s1, s2 or s3 regarding the smoke production and an additional classification of d0, d1 or d2 regarding the production of flaming droplets and/or particles. Additional classifications s1, s2, s3 for smoke production are deduced from the measuring data obtained from testing in accordance with EN 13823 [42]. Additional classifications d0, d1, d2 for flaming droplets/particles are deduced from observations of flaming droplets and particles. For the E class is provided one single subclass d2, while for flooring products is provided the additional classification "s" for smoke emissions only.

Table 2.49 – Additional class regarding the smoke emission and the products of flaming droplets/particles.

Additional class			Level definition
Smoke emission during combustion	**s**	1	Quantity/ speed of emission absent or weak
		2	Quantity/ speed of emission of average intensity

		3	Quantity/ speed of emission of high intensity
Production of flaming droplets/particles during combustion	**d**	0	No dripping
		1	Slow dripping
		2	High dripping

As a conclusion, the following classes for construction products, excluding floorings and linear pipe thermal insulation products are covered by EN 13501-1.

Table 2.50 – Classification according to European Standard EN 13501-1 [41].

Definition	Construction products			Floorings	
Non-combustible materials	A1			$A1_{fl}$	
	A2 – s1 d0	A2 – s1 d1	A2 – s1 d2	$A2_{fl}$ – s1	$A2_{fl}$ – s2
	A2 – s2 d0	A2 – s2 d1	A2 – s2 d2		
	A2 – s3 d0	A2 – s3 d1	A2 – s3 d2		
Combustible materials – very limited contribution to fire	B – s1 d0	B – s1 d1	B – s1 d2	B_{fl} – s1	B_{fl} – s2
	B – s2 d0	B – s2 d1	B – s2 d2		
	B – s3 d0	B – s3 d1	B – s3 d2		
Combustible materials –limited contribution to fire	C – s1 d0	C – s1 d1	C – s1 d2	C_{fl} – s1	C_{fl} – s2
	C – s2 d0	C – s2 d1	C – s2 d2		
	C – s3 d0	C – s3 d1	C – s3 d2		
Combustible materials –medium contribution to fire	B_{fl} – s2	D – s1 d1	D – s1 d2	D_{fl} – s1	D_{fl} – s2
	D – s2 d0	D – s2 d1	D – s2 d2		
	D – s3 d0	D – s3 d1	D – s3 d2		
Combustible materials –highly contribution to fire	E		E-d2	E_{fl}	
Combustible materials – easily flammable	F			F_{fl}	

2.7.2. Resistance to fire

The EN 13501-2 standard specifies the procedure for classification of construction products and building elements using data from fire resistance and smoke leakage tests which are within the direct field of application of the relevant test method. This European Standard deals with:

a) loadbearing elements without a fire separating function
b) loadbearing elements with a fire separating function, with or without glazing, services and fixtures
c) products and systems for protecting elements or parts of the works
d) non-loadbearing elements or parts of works, with or without glazing, services and fixtures
e) wall and ceiling coverings with fire protection ability

The required characteristics of construction products and building elements that need to be assessed are loadbearing capacity and/or integrity and/or insulation. Further optional characteristics are also radiation, mechanical aspects, self-closing ability and smoke leakage. The need to classify based on these optional characteristics is dependent on national regulations and may be specified under certain conditions for certain elements.

Table 2.51 - Resistance to fire required performance characteristics [43].

Designatory letter	Resistance to fire performance	Description
R	**Loadbearing capacity**	The ability of the element of construction to withstand fire exposure under specified mechanical actions, on one or more faces, for a period of time, without any loss of structural stability
E	**Integrity**	The ability of the element of construction that has a separating function, to withstand fire exposure on one side only, without the transmission of fire to the unexposed side as a result of the passage of flames or hot gases. They may cause ignition either of the unexposed surface or of any material adjacent to that surface.
I	**Thermal insulation**	The ability of the element of construction to withstand fire exposure on one side only, without the transmission of fire as a result of significant transfer of heat from the exposed side to the unexposed side.

Combinations of these designatory letters (R, E, I), as appropriate, shall be used as part of the classification of fire performance. They shall be supplemented by the time, in elapsed completed minutes of the nearest lower class during which the functional requirements are satisfied. Additionally, the load level shall be specified.

The standard temperature/time tests shall be carried out and for each test the times shall be determined, in elapsed minutes, for which the test specimen continues to satisfy the different aspects of the performance criteria.

For any of the tests and criteria R, E, I, the obtained times in minutes shall be rounded down to the nearest lower value included in the following series: 10, 15, 20, 30, 45, 60, 90, 120, 180, 240 and 360 min. Failure of the loadbearing capacity criterion shall also be considered as failure of integrity.

Classification for integrity (E) shall be according to whether or not the element is also classified for insulation (I). Where an element is classified both for integrity and insulation, the value of integrity is that determined by whichever of the three aspects fails first. Where an element is classified without an insulation classification (i.e. for the classifications E, RE), the value of integrity is that determined by the time to failure of only the cracks/openings or sustained flaming aspects, whichever fails first. In general, the classes shall be expressed as follows:

Table 2.52 - Classification of fire performance using combinations of designatory letters and time.

For loadbearing elements	
REI tt	tt being the classification period during which all criteria loadbearing capacity, integrity and thermal insulation are satisfied
RE tt	tt being the classification period during which the criteria loadbearing capacity and integrity are satisfied
R tt	tt being the classification period during which the criterion loadbearing capacity is satisfied
For non-loadbearing elements:	
EI tt	tt being the classification period during which the criteria integrity and thermal insulation are satisfied
E tt	tt being the classification period during which the criterion integrity is satisfied

For instance, a building element with a loadbearing capacity of 155 min, an integrity by the cotton pad of 80 min, integrity by cracks/flaming of 85 min and a thermal insulation of 42 min shall be classified REI 30/RE 60/R 120.

EN 1634-1:2014 in conjunction with EN 1363-1 specifies a method for determining the fire resistance of door and shutter assemblies and openable windows designed for installation within openings incorporated in vertical separating elements. The Table 2.53 shows the criteria and standards regarding the test conditions, test specimen, installation of test specimen, conditioning of the test specimen and the application of instrumentation.

Table 2.53 – The criteria and standards for the test procedure.

Test Procedure	Standards
Test equipment	EN 1363-1, and if applicable EN 1363-2
Test conditions	
Mechanical pre-test conditioning	EN 14600
Heating conditions	EN 1363-1 or, if applicable, EN 1363-2
Pressure conditions	EN 1363-1 or, if applicable, EN 1363-2
Furnace atmosphere	EN 1363-1 or, if applicable, EN 1363-2
Test specimen	
Selection of test specimen	EN 14600 and the EN 15269
Size	The test specimen and all its components shall be full size unless limited by the size of the front opening of the furnace which will normally be 3,0 m x 3,0 m. Doorsets and openable windows which cannot be tested at full size shall normally be tested to the maximum size possible
Number of test specimens	EN 1363-1
Design	EN 15269
Construction	EN 1363-1
Installation of test specimen	The test specimen shall be installed, as far as possible, in a manner representative of its use in practice
Supporting construction	EN 1363-1
Conditioning	
Moisture content	EN 1363-1
Mechanical	EN 14600
Application of instrumentation	
Thermocouples	EN 1363-1
Pressure	EN 1363-1

According to Greek legislation, external walls (loadbearing or non-loadbearing) including any openable windows or doors, have no requirement regarding resistance to fire, with the premise that any adjacent building is at distance >10m. As far as reaction to fire is concerned, external walls of hospitals should meet a “**C-s2, d2**” classification.

2.8. Review of standards and EU regulatory requirements for adaptive glazing

So far, no European standard or regulation concerning specifically adaptive glazing has been published. The necessary calculations and specifications, are described by the general window standards, presented in section 2.6.

The only regulation that refers specifically to adaptive glazing is the international standard “ISO 18543 - Glass in building - Electrochromic glazings - Accelerated ageing test and requirements” [44]. This standard specifies the accelerated ageing test and requirements for electrochromic (EC) glazings. The test method described in the document is only applicable to chromogenic glazings that can be switched using an electrical stimulus from high to low transmission states and vice versa. Therefore, the test method is not applicable to other chromogenic glazings, such as photochromic and thermochromic glazings, which do not respond to electrical stimulus. The test method is applicable to any electrochromic glazing fabricated for vision glass (e.g. insulating glass unit, laminated glass) for use in buildings such as doors, windows, skylights and exterior wall systems and glazing exposed to solar radiation. The layers used for constructing the EC glazing and for electrochromically changing the optical properties can be inorganic or organic materials.

Moreover, relevant standards were summarized in previous section (Table 2.38). Among them, the most important and mandatory standards for CE marking are ISO 12543-4, ISO 14449 and ISO 20492, because the final product is an IGU with electrochromic and thermochromic laminated glasses.

3. Requirements for the two demonstration sites of Switch2Save

3.1. Specific comfort requirements (thermal and acoustic comfort)

General State Hospital of Nikaia - "Agios Panteleimon" (NHOSP) is a fully operational hospital located in Nikaia, a suburb in the north part of Piraeus. NHOSP is the second largest hospital in the area of Balkans, operating multiple intensive care and special care units. The Switch2save concept will be implemented in four clinics with great sensitivity with south orientation, where indoor conditions are of outmost importance.

- Neonatal intensive care unit (n - ICU)
- Pediatric surgery clinic (PSC)
- The intensive care unit (ICU)
- The High Dependency Unit (HDU)

3.1.1. NTUA Mock-up building

The mock-up building is a demonstrator located in NTUA campus used only for experimental purposes within. For this reason, there is not any specific comfort requirement.

3.1.2. Nikaia Hospital (NHOSP)

3.1.2.1. Thermal indoor conditions

According to the Greek National legislation for energy systems installations in hospital departments, specific requirements regarding the indoor ambient temperature and the relative humidity have to be taken into account [45, 46]. For all representative clinics of NHOSP, temperature for dressing rooms, public WCs and WCs of the units must be at 22°C. For the rest of the occupied spaces, temperature and relative humidity for cooling and heating must be as shown in the Table 3.1.

Table 3.1 - Temperature and Relative Humidity for Hospital Occupied Spaces [45, 46].

Units	Spaces	Cooling Period		Heating Period	
		Temperature [°C]	Humidity [%]	Temperature [°C]	Humidity [%]
n-ICU ICU HDU	Bed Units	26	50	24	55
	Other occupied Spaces	24	50	22	60
PSC	Occupied Spaces	26	50	22	40

For Greece, national regulation for the energy performance of buildings, determines the operative temperature, air humidity and ventilation for comfort design.

Table 3.2 - Recommended design values of the indoor temperature and air humidity [45, 46].

Type of building/space	Operative Temperature [°C]		Air Humidity [%]	
	Winter season	Summer season	Winter Season	Summer Season
Hospital, health clinic	22	26	35	50
Sickroom	22	25	35	50
Surgery room	18	20	35	55
Outpatient clinic area	20	26	35	50
Waiting room	20	26	35	50
Regional medical center	22	26	35	50
Psychiatric hospital, chronically ill institution, rest home, nursery	22	26	35	50

3.1.2.2. Ventilation

Concerning the air ventilation of the representative clinics of NHOSP,Table 3.3 and Table 3.4 show the air intake and discharge needs for each of the spaces.

Table 3.3 Ventilation for n-ICU/ICU and HDU [45, 46].

Spaces	Air Intake / Air discharge	Comments
Clean Clothes Repository rooms	Air intake: 5 ACH	Through a ceiling diffuser with HEPA H14 filter according to EN 1822
General repository rooms and locker rooms occupied spaces	Air discharge: 5 ACH	
Dirty Clothes Repository rooms	Air discharge: 10 ACH	
Public WC	Air discharge: 60 ACH m^3/h	Above all toilet sheets/showers/urinals units
Private WC	Air discharge: 90 ACH m^3/h	
Occupied spaces with WC	Air intake: 5 ACH Air discharge: 90% of air intake	Through a ceiling diffuser with HEPA H14 filter, from WC, according to EN 1822
Bed units	Air intake: 10 ACH Air discharge: 90% of air intake	Air intake through a ceiling diffuser with HEPA H14 filter according to EN 1822. Air discharge though orifices close to the floor behind the beds.
Quarantine rooms	Air intake: 10 ACH Air discharge: 120% of air intake	Air intake through a ceiling diffuser with HEPA H14 filter according to EN 1822. Air discharge though orifices close to the floor behind the beds.

Table 3.4 - Ventilation for PSC [45, 46].

Spaces	Air Intake / Air discharge	Comments
Clean Clothes Repository rooms	Air intake: 5 ACH	
General repository rooms and locker rooms occupied spaces	Air discharge: 3 ACH	
Dirty Clothes Repository rooms	Air discharge: 10 ACH	
Public WC	Air discharge: 60 ACH m^3/h	Above all toilet sheets/showers/urinals units
Private WC	Air discharge: 90 ACH m^3/h	
Occupied spaces with WC	Air intake: 3 ACH Air discharge: 90% of air intake	
Quarantine rooms	Air intake: 3 ACH Air discharge: 120% of air intake	Air intake through a ceiling diffuser with HEPA H14 filter according to EN 1822. Air discharge though orifices close to the floor behind the beds.
Other Spaces	Air intake: 3 ACH Air discharge: 90% of air intake	Except from the corridors

The volume from air intake from the repository rooms, locker rooms, patient’s WC, dirty clothes repository rooms, public WC, and corridors must be equal to the volume from the air discharge.

3.1.2.3. Acoustic Comfort

For workplaces and Neonatal intensive care units noise level should not be over 40db, while on bed units and staff's bedrooms, should not be over 35db [46]. Commercially available double and triple pane windows fulfill these requirements.

3.1.3. Vasakronan office building

Swedish guidelines for the indoor climate requirements are released by Swedish HVAC Society – Society of Energy and Environmental Technology (SWEDVAC). In the beginning of the nineties, "R1" was the first version of the Swedish indoor climate guideline published by Swedvac, and it was updated over the next years as to be harmonized with the related international European standards. The document comprises thermal climate, indoor air quality, sound and light as well. The main objective of the new "R1" guideline is to provide guidance for the specification of indoor climate conditions.

3.1.3.1. Thermal indoor conditions

Guidelines regarding thermal climate are based on the PPD/PMV approach, specified by SS EN ISO 7730:2006 standard. PPD index, is used as a parameter to determine a suitable target interval for the operative temperature of a space. SS EN ISO 7730 standard, suggests 6%, 10% and 15% as the maximum allowable PPD-index values in three alternative quality classes. The PPD-index of 6% leads to a very narrow temperature range close to the optimal operative temperature range. For an office, during the summer period, temperature range should be about *24.5± 1.0°C*. The new "R1" guideline comprises two thermal quality classes, TQ1 and TQ2. TQ1 quality class has more sharp requirements for the reduction of the risk of local discomfort.

Table 3.5 - Recommended Operative Temperatures for Office Buildings for both classes TQ1 and TQ2.

Season	Target Values	Deviations	Comments
	Operative Temperature		
Winter	20.0 - 24.0°C	It shall be possible to maintain the indoor temperature below 23°C	1.0clo / 1.2met
Summer	23.0 – 26.0°C	For outdoor conditions above 27°C, indoor temperature should be 3°C below the outdoor temperature.	0.5clo / 1.2met

Table 3.6 - Recommended Operative Temperatures for Office Buildings for both classes TQ1 and TQ2.

Parameters	TQ1	TQ2
Floor temperature	22-26°C	20-26°C
Vertical temperature difference	<2°C	<3°C
Radiant temperature asymmetry	Warm ceiling <5°C Cold wall <10°C	Warm ceiling <5°C Cold wall <10°C
Air velocity (draught risk)	<0.10m/s at 20°C <0.15m/s at 26°C (Draught rating <10%)	<0.15m/s at 20°C <0.25m/s at 26°C (Draught rating <20%)

3.1.3.2. Indoor air quality

R1" guideline, provides recommendations for target values regarding maximum acceptable pollutant concentrations. There are two classes that describe the air quality, AQ1 and AQ2. The recommended target values are the same for both indoor air quality classes. The concentration of carbon dioxide (above the outdoors) is used as the quality measure.

Table 3.7 - Target values regarding maximum acceptance of pollutant concentrations for AQ1 and AQ2 air quality classes.

Substance	Designation	Maximum Concentration	Reference

Radon	Rn	100Bq/m^3	FiSIAQ [47]
Carbon monixide	CO	2mg/m^3	SP, FiSIAQ [47, 48]
Nitrogen dioxide	NO_2	40μg/m^3	WHO, ISIAQ-CIB, Swedish EPA [49-51]
Ozone	O_3	50μg/m^3	FiSIAQ [47]
Formaldehyde	HCHO	50μg/m^3	SP, FiSIAQ [47, 48]
Particulate matter <10μm	PM10	40μg/m^3	FiSIAQ, Swedish EPA [47, 50]
Particulate matter <2.5μm	PM2.5	15μg/m^3	FiSIAQ, ISIAQ-CIB, Swedish EPA [47, 49, 50]

"R1" guideline, also describes the outdoor airflow ventilation which must be selected according to recommendations given by Swedish authorities. According to them, for office buildings and other similar work premises, the outdoor airflow rate should be at least 7 lt/s per person plus 0.35 lt/s per m^2 floor area. If any air filters are needed, these should be at least of class F7, and they should be quality assured.

3.1.3.3. Acoustic Comfort

There are three indoor environmental types regarding acoustic comfort, NQ1, NQ2 and NQ3. "R1" guideline specifies target values regarding noise from installations but also recommending other acoustic qualities according to two Swedish Standards [52, 53].

Table 3.8 - Recommended target values regarding noise from installations in offices.

Class	NQ1	NQ2	NQ3
LpA, dB(A)	35	35	35
LpC, dB (C)	55	-	-
LpAFmax, dB(A)	-	-	-

3.2. Lighting requirements and technical challenges in Demonstrators and Mock-up

3.2.1. NTUA Mock-up building

The Mock-up building that is available in the NTUA campus will act as a test bed for the development, the first tests and the fine tuning of the lighting monitoring system. As this mock-up is a scale of a typical building with opening in the envelop, it offers a big potential in the investigation of the effect of the new developed IGU in terms of lighting levels control and the achieved visual comfort.

The challenges raised in Switch2Save and related to the Mock-up in NTUA are the following.

a) Development and setup of an advance monitoring and control system for the combined control of the luminaires and the IGUs
b) Identification of the proper positions that an imaging sensor should be placed in order to achieve the best monitoring of both the task areas and the room openings.
c) Development of a validation method for the lighting monitoring system through image processing algorithms and physical illumination measurements
d) Setup of a test algorithm for the assessment of the achieved lighting levels and the visual comfort
e) Development of a method for the assessment of the IGUs and their contribution to the lighting control parameters
f) Development of a holistic control algorithm that will comprise of an optimized combination on the control of the luminaire and the IGUs
g) Long term assessment of the lighting monitoring system together with the monitor system for the thermal and air comfort.

3.2.2. Nikaia Hospital (NHOSP)

The one of the two physical demonstrators is the Hospital of Nikaia (NHOSP). This building serves a specific task that is related to health services and health care. Regarding the lighting, EN 12464-1 defines the corresponding requirements for each distinctive area in the hospital. The Table 3.9 shows the lighting requirements that should be met in a hospital.

Lighting in healthcare areas are of great importance especially in the recent years and the introduction of the Human Centric Lighting. Where a person is ill or reliant on care, light becomes particularly important because it can promote the healing process. The good lighting at work assist in avoiding accidents and, in the long term, contributes to a healthy life. So, light plays an important role in occupational health and safety. This applies particularly to workplaces in the healthcare sector, which need to meet special qualitative requirements. From operation rooms and recovery areas to examination and treatment rooms, different solutions are required for different room functions. Lighting design and provision of the right light for the occasion should be ensured.

Table 3.9 - Lighting requirements for hospital buildings according to the EN 12464-1 [18].

Usage	Illuminance E_m [lx]	Uniformity U_o	Glare ratio UGR_L	Colour rendering R_a
Rooms for general use				
Waiting rooms	200	0.40	22	80
Corridors: during the day	100	0.40	22	80
Corridors: cleaning	100	0.40	22	80
Corridors: during the night	50	0.40	22	80
Corridors with multi-purpose use	200	0.60	22	80
Day rooms	200	0.60	22	80
Staff rooms				
Staff office	500	0.60	19	80
Staff rooms	300	0.60	19	80
Wards and maternity wards				
General lighting	100	0.40	19	80
Reading lighting	300	0.70	19	80
Simple examinations	300	0.60	19	80
Examination and treatment	1000	0.70	19	90
Night lighting, observation lighting	5	0.00	---	80
Bathrooms and toilets for patients	200	0.40	22	80
Examination rooms (general)				
General lighting	500	0.60	19	90
Examination and treatment	1000	0.70	19	90
Treatment rooms (general)				
Dialysis	500	0.60	19	80
Dermatology	500	0.60	19	90
Endoscopy rooms	300	0.60	19	80
Piaster rooms	500	0.60	19	80
Medical baths	300	0.60	19	80
Massage and radiotherapy	300	0.60	19	80
Intensive care unit				
General lighting	100	0.60	19	90
Simple examinations	300	0.60	19	90
Examination and treatment	1000	0.70	19	90
Night watch	20	0.00	19	90

One of the main challenges of this project, related to the lighting comfort, is to update and optimise the lighting system of the selected rooms of the NHOSP by using modern state of the art lighting equipment and lighting control system. The lighting design will try to implement the HCL where possible in order to deliver the best available lighting quality to the personnel and the patients throughout the day.

The requirements defined in Table 3.9 should be met for all the selected rooms. An analytical lighting design will take place in order to define the lighting zones, the task areas, and the specific needs per area. This study will define the types and the power of the luminaires needed of the adequate illumination of the rooms.

The daylight potential will be analysed for the typical days of the year taking into account the geometries of the rooms, the dimensions of the windows and the orientation. The initial daylight study will reveal the expected daylight harvesting and the corresponding energy saving in the scenario of using the existing windows. The same study will be repeated when the optical data of the new developed IGUs will be available. The theoretical estimation of the energy savings for both window technologies (old vs new) will be compared to the real energy saving that will achieve in practice during the testing phase on the demonstrator.

Technical challenge for this demonstrator is also the integration of the monitoring and control system of the lighting system. The system, as mentioned, will be developed and tested in the mock-up building in NTUA campus and the knowledge will be transferred into the NHOSP. The required values (i.e. lighting levels, uniformities, colour temperature, etc) will be monitored by an imaging-based sensor that will be placed in each room under control. The feedback of the sensor will trigger the lighting management system to control both the luminaires and the IGUs in order to achieve the best possible lighting quality. This is considered as a significant technological and scientific challenge of the project.

One additional technical challenge is the long-term monitoring and assessment of the IGUs implementation in the test rooms of the hospital. This task will begin with a monitoring period of the existing infrastructure (current lighting system) with the existing windows. The next monitoring period will include the new lighting system and the lighting control system but with the existing windows. Finally, the last and longest monitoring period will include the new lighting and control system combined with the new windows with the developed IGUs. The overall assessment of the monitor period is expected to produce valuable data for the behaviour of the IGUs in the demonstrator as well as in general as an innovative building material.

3.2.3. Vasakronan office building

The office building of Vasakronan in Sweden (VAS) will be the second physical demonstrator of the project. Similarly to NHOSP, the VAS building will act a test bed for the application of the new developed IGUs. From the perspective of the lighting requirements, VAS has its own dedicated requirements according to the EN 12464. Table 3.10 outlines the requirements of the most common areas in an office building that should be met with the combination of the artificial and daylight by utilizing diming luminaires and controlled windows equipped with the new IGUs.

Table 3.10 - Lighting requirements for office buildings according to the EN 12464-1 .

Usage	Illuminance E_m [lx]	Uniformity U_o	Glare ratio UGR_L	Colour rendering R_a
Offices				
Filing, copying, etc.	300	0.40	19	80
Writing, typing, reading	500	0.60	19	80
Technical drawing	750	0.70	16	80
CAD workstations	500	0.60	19	80
Conference and meeting rooms	500	0.60	19	80
Reception desk	300	0.60	22	80
Archives	200	0.40	25	80
Rest, sanitation and first aid rooms				
Canteens, pantries	200	0.40	22	---
Rest rooms	100	0.40	22	---
Rooms for physical exercise	300	0.40	22	---

Cloakrooms, washrooms, bathrooms	200	0.40	25	---
Sick bay	500	0.60	19	---
Rooms for medical attention	500	0.60	16	---
Traffic zones inside buildings				
Circulation areas and corridors	100	0.40	28	40
Stairs, escalators, travellators	100	0.40	25	40
Elevators, lifts	100	0.40	25	40
Loading ramps/bays	150	0.40	25	40

3.3. Design, dimensions

See specification sheets.

4. Conclusions

Deliverable D1.1 overviewed and identified building design related requirements, regulatory boundary conditions and specifications generally for office buildings in the target countries and specifically for the two demonstration buildings of the Switch2Save project. Such requirements and conditions were selected considering the most relative available literature and standards. Detailed "specification sheets" were configured and filled with the information gathered for the two physical demonstration sites in frame of this deliverable and are presented in Appendix A.

5. Appendix A: Specification Sheets

The specification sheets will be continuously updated with new data.

5.1. NTUA mock-up building

5.1.1. Reference case

Window ID	Orientation	Type	Window Dimensions			Weight [kg/m^2]
			Height [m]	Width [m]	Overall Thickness [mm]	
WD1	South	Triple	1.179	0.839	84	-
WD2	South	Triple	2.150	0.839	84	-
WD3	West	Triple	1.180	0.827	84	-

Window ID	U_g [W/m^{2}K]	U_f [W/m^{2}K]	U_w [W/m^{2}K]	g-value [-]
WD1	1.7	0.91	1.41 (DIN 10077) | 1.50 (DIN 4108)	0.38 (EN 410) | 0.36 (ISO 9050)
WD2	1.7	0.91	1.45 (DIN 10077) | 1.50 (DIN 4108)	0.38 (EN 410) | 0.36 (ISO 9050)
WD3	1.7	0.91	1.41 (DIN 10077) | 1.50 (DIN 4108)	0.38 (EN 410) | 0.36 (ISO 9050)

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
WD1	0.49	0.89	-	NPD	NPD	NPD
WD2	0.49	0.89	-	NPD	NPD	NPD
WD3	0.49	0.89	-	NPD	NPD	NPD

5.1.2. Regulations

Window ID	Orientation	Type	Window Dimensions			Weight [kg/m^2]
			Height [m]	Width [m]	Overall Thickness [mm]	
WD1	South	Triple	1.179	0.839	84	-
WD2	South	Triple	2.150	0.839	84	-
WD3	West	Triple	1.180	0.827	84	-

Window ID	U_g [W/m^{2}K]	U_f [W/m^{2}K]	U_w [W/m^{2}K]	g-value [-]
WD1	1.1	1.8	-	-
WD2	1.1	1.8	-	-
WD3	1.1	1.8	-	-

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
WD1	-	80	-	NPD	NPD	30
WD2	-	80	-	NPD	NPD	30
WD3	-	80	-	NPD	NPD	30

5.1.3. Expected case

Window ID	Orientation	Type	Window Dimensions			Weight [kg/m^2]
			Height [m]	Width [m]	Overall Thickness [mm]	
WD1	South	Triple	1.179	0.839	84	NPD
WD2	South	Triple	2.150	0.839	84	NPD
WD3	West	Triple	1.180	0.827	84	NPD

Window ID	U_g [W/m^{2}K]	U_f [W/m^{2}K]	U_w [W/m^{2}K]	g-value [-]
WD1	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10
WD2	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10
WD3	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection			Air Permeability class
				E	EW	EI	
WD1	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
WD2	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
WD3	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

5.2. Nikaia Hospital (NHOSP)

Explanation of Window ID nomenclature: AAA . BB . CC . DD or AAA . BB . CC

Part of Window ID	Explanation	Example
AAA	Clinic	Neonatal Intensive Care Unit (NICU) Paediatric surgery / Paediatric Clinic (PS) High Dependency Unit (HDU)
BB	Number of room	01 to 11
CC	Number of opening	01 to 03
DD	Number of window wings	01 to 04 (if it missing means single wing window)

5.2.1. Reference case

5.2.1.1. Neonatal Intensive Care Unit

Neonatal Intensive Care Unit					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
NICU.01.01	S	double glazing, sliding balcony door, metal frame	2.315	2.145	
NICU.01.02	S	double glazing, sliding balcony door, metal frame	2.315	2.145	
NICU.02.01	S	double glazing, sliding balcony door, metal frame	2.315	2.14	
NICU.02.01	S	double glazing, sliding balcony door, metal frame	2.315	2.14	
NICU.03.01	S	double glazing, sliding balcony door, metal frame	2.295	2.16	
NICU.03.01	S	double glazing, sliding balcony door, metal frame	2.295	2.16	
NICU.04.01	S	double glazing, sliding window, metal frame	1.505	2.15	
NICU.04.02	S	double glazing, sliding window, metal frame	1.505	2.15	
NICU.05.01.01	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.01.02	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.01.03	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.02.01	S	double glazing, sliding window, metal frame	1.505	1.835	
NICU.05.02.02	S	double glazing, sliding window, metal frame	1.505	1.835	
NICU.06.01.01	S	double glazing, sliding window, metal frame	1.505	2.955	

NICU.06.01.02	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.01.03	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.01	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.02	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.03	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.03.01	S	double glazing, sliding window, metal frame	1.5	2.95	
NICU.06.03.02	S	double glazing, sliding window, metal frame	1.5	2.95	
NICU.06.03.03	S	double glazing, sliding window, metal frame	1.5	2.95	
NICU.07.01.01	S	double glazing, sliding window, metal frame	1.5	1.56	
NICU.07.01.02	S	double glazing, sliding window, metal frame	1.5	1.56	
NICU.07.02.01	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.02.02	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.02.03	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.03.01	W	double glazing, stable window, metal frame	0.33	1.225	
NICU.07.04.01	W	double glazing, stable window, metal frame	0.33	2.2	
NICU.07.04.02	W	double glazing, stable window, metal frame	0.33	2.2	
NICU.08.01	W	double glazing, opening balcony door, metal frame	2.25	1.855	
NICU.08.02	W	double glazing, opening balcony door, metal frame	2.25	1.855	

Neonatal Intensive Care Unit					
Window ID	**U_g [W/m^{2}K]**	**U_f [W/m^{2}K]**	**U_w [W/m^{2}K]**	**g-value [-]**	**Frame Colour**
NICU.01.01	2.8	7	3.7		blue
NICU.01.02	2.8	7	3.7		blue
NICU.02.01	2.8	7	3.7		blue
NICU.02.01	2.8	7	3.7		blue
NICU.03.01	2.8	7	3.7		blue
NICU.03.01	2.8	7	3.7		blue
NICU.04.01	2.8	7	3.7		blue

NICU.04.02	2.8	7	3.7		blue
NICU.05.01.01	2.8	7	3.7		blue
NICU.05.01.02	2.8	7	3.7		blue
NICU.05.01.03	2.8	7	3.7		blue
NICU.05.02.01	2.8	7	3.7		blue
NICU.05.02.02	2.8	7	3.7		blue
NICU.06.01.01	2.8	7	3.7		blue
NICU.06.01.02	2.8	7	3.7		blue
NICU.06.01.03	2.8	7	3.7		blue
NICU.06.02.01	2.8	7	3.7		blue
NICU.06.02.02	2.8	7	3.7		blue
NICU.06.02.03	2.8	7	3.7		blue
NICU.06.03.01	2.8	7	3.7		blue
NICU.06.03.02	2.8	7	3.7		blue
NICU.06.03.03	2.8	7	3.7		blue
NICU.07.01.01	2.8	7	3.7		blue
NICU.07.01.02	2.8	7	3.7		blue
NICU.07.02.01	2.8	7	3.7		blue
NICU.07.02.02	2.8	7	3.7		blue
NICU.07.02.03	2.8	7	3.7		blue
NICU.07.03.01	2.8	7	3.7		blue
NICU.07.04.01	2.8	7	3.7		blue
NICU.07.04.02	2.8	7	3.7		blue
NICU.08.01	2.8	7	3.7		blue
NICU.08.02	2.8	7	3.7		blue

Neonatal Intensive Care Unit						
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
NICU.01.01				NPD	NPD	NPD
NICU.01.02				NPD	NPD	NPD
NICU.02.01				NPD	NPD	NPD
NICU.02.01				NPD	NPD	NPD
NICU.03.01				NPD	NPD	NPD
NICU.03.01				NPD	NPD	NPD
NICU.04.01				NPD	NPD	NPD
NICU.04.02				NPD	NPD	NPD
NICU.05.01.01				NPD	NPD	NPD
NICU.05.01.02				NPD	NPD	NPD
NICU.05.01.03				NPD	NPD	NPD
NICU.05.02.01				NPD	NPD	NPD
NICU.05.02.02				NPD	NPD	NPD
NICU.06.01.01				NPD	NPD	NPD
NICU.06.01.02				NPD	NPD	NPD
NICU.06.01.03				NPD	NPD	NPD

NICU.06.02.01				NPD	NPD	NPD
NICU.06.02.02				NPD	NPD	NPD
NICU.06.02.03				NPD	NPD	NPD
NICU.06.03.01				NPD	NPD	NPD
NICU.06.03.02				NPD	NPD	NPD
NICU.06.03.03				NPD	NPD	NPD
NICU.07.01.01				NPD	NPD	NPD
NICU.07.01.02				NPD	NPD	NPD
NICU.07.02.01				NPD	NPD	NPD
NICU.07.02.02				NPD	NPD	NPD
NICU.07.02.03				NPD	NPD	NPD
NICU.07.03.01				NPD	NPD	NPD
NICU.07.04.01				NPD	NPD	NPD
NICU.07.04.02				NPD	NPD	NPD
NICU.08.01				NPD	NPD	NPD
NICU.08.02				NPD	NPD	NPD

5.2.1.2. Pediatric surgery / Pediatric Clinic

Pediatric surgery / Pediatric Clinic					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
PS.01.01	S	double glazing, sliding window, metal frame	1.495	2.19	
PS.01.02	S	double glazing, sliding window, metal frame	1.495	2.19	
PS.02.01	S	double glazing, sliding window, metal frame	1.495	1.93	
PS.02.02	S	double glazing, sliding window, metal frame	1.495	1.93	
PS.03.01	S	double glazing, sliding window, metal frame	1.49	2.13	
PS.03.02	S	double glazing, sliding window, metal frame	1.49	2.13	
PS.04.01	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.04.02	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.05.01.01	S	double glazing, sliding window, metal frame	1.495	1.37	
PS.05.01.02	S	double glazing, sliding window, metal frame	1.495	1.37	
PS.05.02.01	S	double glazing, sliding window, metal frame	1.495	1.355	
PS.05.02.02	S	double glazing, sliding window, metal frame	1.495	1.355	
PS.06.01	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.06.02	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.07.01	S	double glazing, sliding window, metal frame	1.49	2.145	
PS.07.02	S	double glazing, sliding window, metal frame	1.49	2.145	
PS.08.01	S	double glazing, sliding balcony door, metal frame	2.43	1.755	
PS.08.02	S	double glazing, sliding balcony door, metal frame	2.43	1.755	
PS.09.01	S	double glazing, sliding balcony door, metal frame	2.43	1.76	
PS.09.02	S	double glazing, sliding balcony door, metal frame	2.43	1.76	
PS.10.01.01	S	double glazing, sliding window, metal frame	1.49	2.14	
PS.10.01.02	S	double glazing, sliding window, metal frame	1.49	2.14	

PS.10.02.01	W	double glazing, sliding window, metal frame	149.5	2.15	
PS.10.02.02	W	double glazing, sliding window, metal frame	149.5	2.15	
PS.11.01.01	W	double glazing, sliding window, metal frame	1.49	1.83	
PS.11.01.02	W	double glazing, sliding window, metal frame	1.49	1.83	
PS.11.02.01	W	double glazing, sliding window, metal frame	1.49	1.835	
PS.11.02.02	W	double glazing, sliding window, metal frame	1.49	1.835	
PS.11.03.01	N	double glazing, sliding window, metal frame	1.5	2.925	
PS.11.03.02	N	double glazing, sliding window, metal frame	1.5	2.925	
PS.11.03.02	N	double glazing, sliding window, metal frame	1.5	2.925	

Pediatric surgery / Pediatric Clinic					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
PS.01.01	2.8	7	3.7		blue
PS.01.02	2.8	7	3.7		blue
PS.02.01	2.8	7	3.7		blue
PS.02.02	2.8	7	3.7		blue
PS.03.01	2.8	7	3.7		blue
PS.03.02	2.8	7	3.7		blue
PS.04.01	2.8	7	3.7		blue
PS.04.02	2.8	7	3.7		blue
PS.05.01.01	2.8	7	3.7		blue
PS.05.01.02	2.8	7	3.7		blue
PS.05.02.01	2.8	7	3.7		blue
PS.05.02.02	2.8	7	3.7		blue
PS.06.01	2.8	7	3.7		blue
PS.06.02	2.8	7	3.7		blue
PS.07.01	2.8	7	3.7		blue
PS.07.02	2.8	7	3.7		blue
PS.08.01	2.8	7	3.7		blue
PS.08.02	2.8	7	3.7		blue
PS.09.01	2.8	7	3.7		blue
PS.09.02	2.8	7	3.7		blue
PS.10.01.01	2.8	7	3.7		blue
PS.10.01.02	2.8	7	3.7		blue
PS.10.02.01	2.8	7	3.7		blue
PS.10.02.02	2.8	7	3.7		blue
PS.11.01.01	2.8	7	3.7		blue
PS.11.01.02	2.8	7	3.7		blue

PS.11.02.01	2.8	7	3.7		blue
PS.11.02.02	2.8	7	3.7		blue
PS.11.03.01	2.8	7	3.7		blue
PS.11.03.02	2.8	7	3.7		blue
PS.11.03.02	2.8	7	3.7		blue

Pediatric surgery / Pediatric Clinic						
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
PS.01.01				NPD	NPD	NPD
PS.01.02				NPD	NPD	NPD
PS.02.01				NPD	NPD	NPD
PS.02.02				NPD	NPD	NPD
PS.03.01				NPD	NPD	NPD
PS.03.02				NPD	NPD	NPD
PS.04.01				NPD	NPD	NPD
PS.04.02				NPD	NPD	NPD
PS.05.01.01				NPD	NPD	NPD
PS.05.01.02				NPD	NPD	NPD
PS.05.02.01				NPD	NPD	NPD
PS.05.02.02				NPD	NPD	NPD
PS.06.01				NPD	NPD	NPD
PS.06.02				NPD	NPD	NPD
PS.07.01				NPD	NPD	NPD
PS.07.02				NPD	NPD	NPD
PS.08.01				NPD	NPD	NPD
PS.08.02				NPD	NPD	NPD
PS.09.01				NPD	NPD	NPD
PS.09.02				NPD	NPD	NPD
PS.10.01.01				NPD	NPD	NPD
PS.10.01.02				NPD	NPD	NPD
PS.10.02.01				NPD	NPD	NPD
PS.10.02.02				NPD	NPD	NPD
PS.11.01.01				NPD	NPD	NPD
PS.11.01.02				NPD	NPD	NPD
PS.11.02.01				NPD	NPD	NPD
PS.11.02.02				NPD	NPD	NPD
PS.11.03.01				NPD	NPD	NPD
PS.11.03.02				NPD	NPD	NPD
PS.11.03.02				NPD	NPD	NPD

5.2.1.3. High Dependency Unit

High Dependency Unit					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
HDU.01.01.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.01.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.02.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening balcony door	2.91	1.355	
HDU.01.02.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening balcony door	2.91	1.355	
HDU.01.03.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.03.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.02.01	W	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.84	0.945	
HDU.02.02	W	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.84	0.945	

High Dependency Unit					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
HDU.01.01.01	2.8	7	3.7		white
HDU.01.01.02	2.8	7	3.7		white
HDU.01.02.01	2.8	7	3.7		white
HDU.01.02.02	2.8	7	3.7		white
HDU.01.03.01	2.8	7	3.7		white
HDU.01.03.02	2.8	7	3.7		white
HDU.02.01	2.8	7	3.7		white
HDU.02.02	2.8	7	3.7		white

High Dependency Unit						
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
HDU.01.01.01				NPD	NPD	NPD
HDU.01.01.02				NPD	NPD	NPD
HDU.01.02.01				NPD	NPD	NPD
HDU.01.02.02				NPD	NPD	NPD
HDU.01.03.01				NPD	NPD	NPD
HDU.01.03.02				NPD	NPD	NPD
HDU.02.01				NPD	NPD	NPD
HDU.02.02				NPD	NPD	NPD

5.2.2. Regulations

5.2.2.1. Neonatal Intensive Care Unit

Neonatal Intensive Care Unit					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
NICU.01.01	S	double glazing, sliding balcony door, metal frame	2.315	2.145	
NICU.01.02	S	double glazing, sliding balcony door, metal frame	2.315	2.145	
NICU.02.01	S	double glazing, sliding balcony door, metal frame	2.315	2.14	
NICU.02.01	S	double glazing, sliding balcony door, metal frame	2.315	2.14	
NICU.03.01	S	double glazing, sliding balcony door, metal frame	2.295	2.16	
NICU.03.01	S	double glazing, sliding balcony door, metal frame	2.295	2.16	
NICU.04.01	S	double glazing, sliding window, metal frame	1.505	2.15	
NICU.04.02	S	double glazing, sliding window, metal frame	1.505	2.15	
NICU.05.01.01	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.01.02	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.01.03	S	double glazing, sliding window, metal frame	1.51	2.955	
NICU.05.02.01	S	double glazing, sliding window, metal frame	1.505	1.835	
NICU.05.02.02	S	double glazing, sliding window, metal frame	1.505	1.835	
NICU.06.01.01	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.01.02	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.01.03	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.01	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.02	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.02.03	S	double glazing, sliding window, metal frame	1.505	2.955	
NICU.06.03.01	S	double glazing, sliding window, metal frame	1.5	2.95	
NICU.06.03.02	S	double glazing, sliding window, metal frame	1.5	2.95	
NICU.06.03.03	S	double glazing, sliding window, metal frame	1.5	2.95	

NICU.07.01.01	S	double glazing, sliding window, metal frame	1.5	1.56	
NICU.07.01.02	S	double glazing, sliding window, metal frame	1.5	1.56	
NICU.07.02.01	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.02.02	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.02.03	S	double glazing, sliding window, metal frame	1.5	2.96	
NICU.07.03.01	W	double glazing, stable window, metal frame	0.33	1.225	
NICU.07.04.01	W	double glazing, stable window, metal frame	0.33	2.2	
NICU.07.04.02	W	double glazing, stable window, metal frame	0.33	2.2	
NICU.08.01	W	double glazing, opening balcony door, metal frame	2.25	1.855	
NICU.08.02	W	double glazing, opening balcony door, metal frame	2.25	1.855	

Neonatal Intensive Care Unit					
Window ID	**U_g [W/m^{2}K]**	**U_f [W/m^{2}K]**	**U_w [W/m^{2}K]**	**g-value [-]**	**Frame Colour**
NICU.01.01			2.6		blue
NICU.01.02			2.6		blue
NICU.02.01			2.6		blue
NICU.02.01			2.6		blue
NICU.03.01			2.6		blue
NICU.03.01			2.6		blue
NICU.04.01			2.6		blue
NICU.04.02			2.6		blue
NICU.05.01.01			2.6		blue
NICU.05.01.02			2.6		blue
NICU.05.01.03			2.6		blue
NICU.05.02.01			2.6		blue
NICU.05.02.02			2.6		blue
NICU.06.01.01			2.6		blue
NICU.06.01.02			2.6		blue
NICU.06.01.03			2.6		blue
NICU.06.02.01			2.6		blue
NICU.06.02.02			2.6		blue
NICU.06.02.03			2.6		blue
NICU.06.03.01			2.6		blue
NICU.06.03.02			2.6		blue
NICU.06.03.03			2.6		blue
NICU.07.01.01			2.6		blue
NICU.07.01.02			2.6		blue

NICU.07.02.01			2.6		blue
NICU.07.02.02			2.6		blue
NICU.07.02.03			2.6		blue
NICU.07.03.01			2.6		blue
NICU.07.04.01			2.6		blue
NICU.07.04.02			2.6		blue
NICU.08.01			2.6		blue
NICU.08.02			2.6		blue

Neonatal Intensive Care Unit						
Window ID	**τ_{vis} [R_a]**	**R_a**	**Haze**	**Fire Protection**		
				E	**EW**	**EI**
NICU.01.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.01.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.02.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.02.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.03.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.03.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.04.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.04.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.05.01.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.05.01.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.05.01.03	NPD	NPD	NPD	NPD	NPD	NPD
NICU.05.02.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.05.02.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.01.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.01.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.01.03	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.02.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.02.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.02.03	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.03.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.03.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.06.03.03	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.01.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.01.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.02.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.02.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.02.03	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.03.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.04.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.07.04.02	NPD	NPD	NPD	NPD	NPD	NPD
NICU.08.01	NPD	NPD	NPD	NPD	NPD	NPD
NICU.08.02	NPD	NPD	NPD	NPD	NPD	NPD

5.2.2.2. Pediatric surgery / Pediatric Clinic

Pediatric surgery / Pediatric Clinic					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
PS.01.01	S	double glazing, sliding window, metal frame	1.495	2.19	
PS.01.02	S	double glazing, sliding window, metal frame	1.495	2.19	
PS.02.01	S	double glazing, sliding window, metal frame	1.495	1.93	
PS.02.02	S	double glazing, sliding window, metal frame	1.495	1.93	
PS.03.01	S	double glazing, sliding window, metal frame	1.49	2.13	
PS.03.02	S	double glazing, sliding window, metal frame	1.49	2.13	
PS.04.01	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.04.02	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.05.01.01	S	double glazing, sliding window, metal frame	1.495	1.37	
PS.05.01.02	S	double glazing, sliding window, metal frame	1.495	1.37	
PS.05.02.01	S	double glazing, sliding window, metal frame	1.495	1.355	
PS.05.02.02	S	double glazing, sliding window, metal frame	1.495	1.355	
PS.06.01	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.06.02	S	double glazing, sliding window, metal frame	1.495	2.155	
PS.07.01	S	double glazing, sliding window, metal frame	1.49	2.145	
PS.07.02	S	double glazing, sliding window, metal frame	1.49	2.145	
PS.08.01	S	double glazing, sliding balcony door, metal frame	2.43	1.755	
PS.08.02	S	double glazing, sliding balcony door, metal frame	2.43	1.755	
PS.09.01	S	double glazing, sliding balcony door, metal frame	2.43	1.76	
PS.09.02	S	double glazing, sliding balcony door, metal frame	2.43	1.76	
PS.10.01.01	S	double glazing, sliding window, metal frame	1.49	2.14	
PS.10.01.02	S	double glazing, sliding window, metal frame	1.49	2.14	

PS.10.02.01	W	double glazing, sliding window, metal frame	149.5	2.15	
PS.10.02.02	W	double glazing, sliding window, metal frame	149.5	2.15	
PS.11.01.01	W	double glazing, sliding window, metal frame	1.49	1.83	
PS.11.01.02	W	double glazing, sliding window, metal frame	1.49	1.83	
PS.11.02.01	W	double glazing, sliding window, metal frame	1.49	1.835	
PS.11.02.02	W	double glazing, sliding window, metal frame	1.49	1.835	
PS.11.03.01	N	double glazing, sliding window, metal frame	1.5	2.925	
PS.11.03.02	N	double glazing, sliding window, metal frame	1.5	2.925	
PS.11.03.02	N	double glazing, sliding window, metal frame	1.5	2.925	

Pediatric surgery / Pediatric Clinic					
Window ID	**U_g [W/m^{2}K]**	**U_f [W/m^{2}K]**	**U_w [W/m^{2}K]**	**g-value [-]**	**Frame Colour**
PS.01.01	NPD	NPD	2.6	NPD	blue
PS.01.02	NPD	NPD	2.6	NPD	blue
PS.02.01	NPD	NPD	2.6	NPD	blue
PS.02.02	NPD	NPD	2.6	NPD	blue
PS.03.01	NPD	NPD	2.6	NPD	blue
PS.03.02	NPD	NPD	2.6	NPD	blue
PS.04.01	NPD	NPD	2.6	NPD	blue
PS.04.02	NPD	NPD	2.6	NPD	blue
PS.05.01.01	NPD	NPD	2.6	NPD	blue
PS.05.01.02	NPD	NPD	2.6	NPD	blue
PS.05.02.01	NPD	NPD	2.6	NPD	blue
PS.05.02.02	NPD	NPD	2.6	NPD	blue
PS.06.01	NPD	NPD	2.6	NPD	blue
PS.06.02	NPD	NPD	2.6	NPD	blue
PS.07.01	NPD	NPD	2.6	NPD	blue
PS.07.02	NPD	NPD	2.6	NPD	blue
PS.08.01	NPD	NPD	2.6	NPD	blue
PS.08.02	NPD	NPD	2.6	NPD	blue
PS.09.01	NPD	NPD	2.6	NPD	blue
PS.09.02	NPD	NPD	2.6	NPD	blue
PS.10.01.01	NPD	NPD	2.6	NPD	blue
PS.10.01.02	NPD	NPD	2.6	NPD	blue
PS.10.02.01	NPD	NPD	2.6	NPD	blue
PS.10.02.02	NPD	NPD	2.6	NPD	blue
PS.11.01.01	NPD	NPD	2.6	NPD	blue
PS.11.01.02	NPD	NPD	2.6	NPD	blue

PS.11.02.01	NPD	NPD	2.6	NPD	blue
PS.11.02.02	NPD	NPD	2.6	NPD	blue
PS.11.03.01	NPD	NPD	2.6	NPD	blue
PS.11.03.02	NPD	NPD	2.6	NPD	blue
PS.11.03.02	NPD	NPD	2.6	NPD	blue

Pediatric surgery / Pediatric Clinic						
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
PS.01.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.01.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.02.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.02.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.03.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.03.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.04.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.04.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.05.01.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.05.01.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.05.02.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.05.02.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.06.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.06.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.07.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.07.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.08.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.08.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.09.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.09.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.10.01.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.10.01.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.10.02.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.10.02.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.01.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.01.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.02.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.02.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.03.01	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.03.02	NPD	NPD	NPD	NPD	NPD	NPD
PS.11.03.02	NPD	NPD	NPD	NPD	NPD	NPD

5.2.2.3. High Dependency Unit

High Dependency Unit					
Window ID	Orientation	Type	Window Dimensions		
			Height [m]	Width [m]	Overall Thickness [mm]
HDU.01.01.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.01.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.02.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening balcony door	2.91	1.355	
HDU.01.02.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening balcony door	2.91	1.355	
HDU.01.03.01	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.01.03.02	S	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.87	1.35	
HDU.02.01	W	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.84	0.945	
HDU.02.02	W	0.2 m box for the shadings 0.5 m double glazing stable window the rest double glazing opening window	1.84	0.945	

High Dependency Unit					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
HDU.01.01.01	NPD	NPD	2.6	NPD	white
HDU.01.01.02	NPD	NPD	2.6	NPD	white
HDU.01.02.01	NPD	NPD	2.6	NPD	white
HDU.01.02.02	NPD	NPD	2.6	NPD	white
HDU.01.03.01	NPD	NPD	2.6	NPD	white
HDU.01.03.02	NPD	NPD	2.6	NPD	white
HDU.02.01	NPD	NPD	2.6	NPD	white
HDU.02.02	NPD	NPD	2.6	NPD	white

High Dependency Unit						
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
HDU.01.01.01	NPD	NPD	NPD	NPD	NPD	NPD
HDU.01.01.02	NPD	NPD	NPD	NPD	NPD	NPD
HDU.01.02.01	NPD	NPD	NPD	NPD	NPD	NPD
HDU.01.02.02	NPD	NPD	NPD	NPD	NPD	NPD
HDU.01.03.01	NPD	NPD	NPD	NPD	NPD	NPD
HDU.01.03.02	NPD	NPD	NPD	NPD	NPD	NPD
HDU.02.01	NPD	NPD	NPD	NPD	NPD	NPD
HDU.02.02	NPD	NPD	NPD	NPD	NPD	NPD

5.2.3. Expected case

5.2.3.1. Neonatal Intensive Care Unit

Neonatal Intensive Care Unit				
Window ID	Orientation	Window Dimensions		
		Height [m]	Width [m]	Overall Thickness [mm]
NICU.01.01	S	2.315	2.145	
NICU.01.02	S	2.315	2.145	
NICU.02.01	S	2.315	2.14	
NICU.02.01	S	2.315	2.14	
NICU.03.01	S	2.295	2.16	
NICU.03.01	S	2.295	2.16	
NICU.04.01	S	1.505	2.15	
NICU.04.02	S	1.505	2.15	
NICU.05.01.01	S	1.51	2.955	
NICU.05.01.02	S	1.51	2.955	
NICU.05.01.03	S	1.51	2.955	
NICU.05.02.01	S	1.505	1.835	
NICU.05.02.02	S	1.505	1.835	
NICU.06.01.01	S	1.505	2.955	
NICU.06.01.02	S	1.505	2.955	
NICU.06.01.03	S	1.505	2.955	
NICU.06.02.01	S	1.505	2.955	
NICU.06.02.02	S	1.505	2.955	
NICU.06.02.03	S	1.505	2.955	
NICU.06.03.01	S	1.5	2.95	
NICU.06.03.02	S	1.5	2.95	
NICU.06.03.03	S	1.5	2.95	
NICU.07.01.01	S	1.5	1.56	
NICU.07.01.02	S	1.5	1.56	
NICU.07.02.01	S	1.5	2.96	
NICU.07.02.02	S	1.5	2.96	
NICU.07.02.03	S	1.5	2.96	
NICU.07.03.01	W	0.33	1.225	
NICU.07.04.01	W	0.33	2.2	
NICU.07.04.02	W	0.33	2.2	
NICU.08.01	W	2.25	1.855	
NICU.08.02	W	2.25	1.855	

Neonatal Intensive Care Unit					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
NICU.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue

NICU.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.04.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.04.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.05.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.05.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.05.01.03	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.05.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.05.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.01.03	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.02.03	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.03.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.06.03.03	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.02.03	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.04.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.07.04.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.08.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
NICU.08.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue

Neonatal Intensive Care Unit							
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection			Air Permeability class
				E	EW	EI	
NICU.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.04.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.04.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.05.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.05.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.05.01.03	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.05.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.05.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

NICU.06.01.03	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.02.03	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.03.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.06.03.03	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.02.03	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.04.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.07.04.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.08.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
NICU.08.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

5.2.3.2. Pediatric surgery / Pediatric Clinic

Pediatric surgery / Pediatric Clinic				
Window ID	Orientation	Window Dimensions		
		Height [m]	Width [m]	Overall Thickness [mm]
PS.01.01	S	1.495	2.19	
PS.01.02	S	1.495	2.19	
PS.02.01	S	1.495	1.93	
PS.02.02	S	1.495	1.93	
PS.03.01	S	1.49	2.13	
PS.03.02	S	1.49	2.13	
PS.04.01	S	1.495	2.155	
PS.04.02	S	1.495	2.155	
PS.05.01.01	S	1.495	1.37	
PS.05.01.02	S	1.495	1.37	
PS.05.02.01	S	1.495	1.355	
PS.05.02.02	S	1.495	1.355	
PS.06.01	S	1.495	2.155	
PS.06.02	S	1.495	2.155	
PS.07.01	S	1.49	2.145	
PS.07.02	S	1.49	2.145	
PS.08.01	S	2.43	1.755	
PS.08.02	S	2.43	1.755	
PS.09.01	S	2.43	1.76	
PS.09.02	S	2.43	1.76	
PS.10.01.01	S	1.49	2.14	
PS.10.01.02	S	1.49	2.14	
PS.10.02.01	W	149.5	2.15	
PS.10.02.02	W	149.5	2.15	
PS.11.01.01	W	1.49	1.83	
PS.11.01.02	W	1.49	1.83	
PS.11.02.01	W	1.49	1.835	
PS.11.02.02	W	1.49	1.835	
PS.11.03.01	N	1.5	2.925	
PS.11.03.02	N	1.5	2.925	
PS.11.03.02	N	1.5	2.925	

Pediatric surgery / Pediatric Clinic					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
PS.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.03.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue

PS.04.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.04.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.05.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.05.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.05.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.05.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.06.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.06.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.07.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.07.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.08.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.08.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.09.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.09.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.10.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.10.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.10.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.10.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.03.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue
PS.11.03.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	blue

Pediatric surgery / Pediatric Clinic							
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection			Air Permeability class
				E	EW	EI	
PS.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.03.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.04.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.04.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.05.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.05.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.05.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.05.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.06.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.06.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.07.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.07.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.08.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.08.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

PS.09.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.09.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.10.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.10.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.10.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.10.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.03.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
PS.11.03.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

5.2.3.3. High Dependency Unit

High Dependency Unit				
Window ID	Orientation	Window Dimensions		
		Height [m]	Width [m]	Overall Thickness [mm]
HDU.01.01.01	S	1.87	1.35	
HDU.01.01.02	S	1.87	1.35	
HDU.01.02.01	S	2.91	1.355	
HDU.01.02.02	S	2.91	1.355	
HDU.01.03.01	S	1.87	1.35	
HDU.01.03.02	S	1.87	1.35	
HDU.02.01	W	1.84	0.945	
HDU.02.02	W	1.84	0.945	

High Dependency Unit					
Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]	Frame Colour
HDU.01.01.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.01.01.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.01.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.01.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.01.03.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.01.03.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.02.01	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white
HDU.02.02	0.5 - 0.7	0.80 – 0.95	0.65 - 0.80	0.40 / 0.10	white

High Dependency Unit							
Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection			Air Permeability class
				E	EW	EI	
HDU.01.01.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.01.01.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.01.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.01.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.01.03.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.01.03.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.02.01	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4
HDU.02.02	0.60 / 0.10	90 - 85	-	NPD	NPD	30	4

5.3. Vasakronan office building

5.3.1. Reference case

Window ID	Orientation	Type	Window Dimensions			Weight $[kg/m^2]$
			Height [m]	Width [m]	Overall Thickness [mm]	
SO01	SE	Double IG	2845	1630	31	37.5
SO02	SE	Double IG	2845	1630	31	37.5
SO03	SE	Double IG	2845	1630	31	37.5
SO04	SE	Double IG	2230	1660	31	37.5
SO05	SE	Double IG	2230	1660	31	37.5
SO06	SE	Double IG	2230	1660	31	37.5
SO7	SE	Double IG	2230	1660	31	37.5
SO8	SE	Double IG	2230	1660	31	37.5
SO9	SE	Double IG	2230	1660	31	37.5
SO10	SE	Double IG	2230	1660	31	37.5
SO11	SE	Double IG	2230	1660	31	37.5
SO12	SE	Double IG	2230	1660	31	37.5
SO13	SE	Double IG	2230	1660	31	37.5
SO14	SE	Double IG	2230	1660	31	37.5
SO15	SE	Double IG	2230	1660	31	37.5
SO16	SE	Double IG	2230	1660	31	37.5
SO17	SE	Double IG	2230	1660	31	37.5
SO18	SE	Double IG	2230	1660	31	37.5
NO01	NE	Double IG	2870	1555	31	37.5
NO02	NE	Double IG	2870	1555	31	37.5
NO03	NE	Double IG	2230	1555	31	37.5
NO04	NE	Double IG	2230	1555	31	37.5
NO05	NE	Double IG	2230	1555	31	37.5
NO06	NE	Double IG	2230	1555	31	37.5
NO07	NE	Double IG	2230	1555	31	37.5
NO08	NE	Double IG	2230	1555	31	37.5
NO09	NE	Double IG	2230	1555	31	37.5
NO10	NE	Double IG	2230	1555	31	37.5
NO11	NE	Double IG	2230	1555	31	37.5
NO12	NE	Double IG	2230	1555	31	37.5
SV01	SV	Double IG	2870	1555	31	37.5
SV02	SV	Double IG	2870	1555	31	37.5
SV05	SV	Double IG	2230	1555	31	37.5
SV06	SV	Double IG	2230	1555	31	37.5
SV09	SV	Double IG	2230	1555	31	37.5
SV10	SV	Double IG	2230	1555	31	37.5
SV13	SV	Double IG	2230	1555	31	37.5
SV14	SV	Double IG	2230	1555	31	37.5
SV17	SV	Double IG	2230	1555	31	37.5
SV18	SV	Double IG	2230	1555	31	37.5
SV21	SV	Double IG	2230	1555	31	37.5
SV22	SV	Double IG	2230	1555	31	37.5

Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]
SO01	1.1	1 – 1.4		59-72%
SO02	1.1	1 - 1.4		59-72%
SO03	1.1	1 - 1.4		59-72%
SO04	1.1	1 - 1.4		59-72%
SO05	1.1	1 - 1.4		59-72%
SO06	1.1	1 - 1.4		59-72%
SO7	1.1	1 - 1.4		59-72%
SO8	1.1	1 - 1.4		59-72%
SO9	1.1	1 - 1.4		59-72%
SO10	1.1	1 - 1.4		59-72%
SO11	1.1	1 - 1.4		59-72%
SO12	1.1	1 - 1.4		59-72%
SO13	1.1	1 - 1.4		59-72%
SO14	1.1	1 - 1.4		59-72%
SO15	1.1	1 - 1.4		59-72%
SO16	1.1	1 - 1.4		59-72%
SO17	1.1	1 - 1.4		59-72%
SO18	1.1	1 - 1.4		59-72%
NO01	1.1	1 - 1.4		59-72%
NO02	1.1	1 - 1.4		59-72%
NO03	1.1	1 - 1.4		59-72%
NO04	1.1	1 - 1.4		59-72%
NO05	1.1	1 - 1.4		59-72%
NO06	1.1	1 - 1.4		59-72%
NO07	1.1	1 - 1.4		59-72%
NO08	1.1	1 - 1.4		59-72%
NO09	1.1	1 - 1.4		59-72%
NO10	1.1	1 - 1.4		59-72%
NO11	1.1	1 - 1.4		59-72%
NO12	1.1	1 - 1.4		59-72%
SV01	1.1	1 - 1.4		59-72%
SV02	1.1	1 - 1.4		59-72%
SV05	1.1	1 - 1.4		59-72%
SV06	1.1	1 - 1.4		59-72%
SV09	1.1	1 - 1.4		59-72%
SV10	1.1	1 - 1.4		59-72%
SV13	1.1	1 - 1.4		59-72%
SV14	1.1	1 - 1.4		59-72%
SV17	1.1	1 - 1.4		59-72%
SV18	1.1	1 - 1.4		59-72%
SV21	1.1	1 - 1.4		59-72%
SV22	1.1	1 - 1.4		59-72%

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
SO01	80%	96%	NPD	NPD	NPD	NPD
SO02	80%	96%	NPD	NPD	NPD	NPD
SO03	80%	96%	NPD	NPD	NPD	NPD
SO04	80%	96%	NPD	NPD	NPD	NPD
SO05	80%	96%	NPD	NPD	NPD	NPD
SO06	80%	96%	NPD	NPD	NPD	NPD
SO7	80%	96%	NPD	NPD	NPD	NPD
SO8	80%	96%	NPD	NPD	NPD	NPD
SO9	80%	96%	NPD	NPD	NPD	NPD
SO10	80%	96%	NPD	NPD	NPD	NPD
SO11	80%	96%	NPD	NPD	NPD	NPD
SO12	80%	96%	NPD	NPD	NPD	NPD
SO13	80%	96%	NPD	NPD	NPD	NPD
SO14	80%	96%	NPD	NPD	NPD	NPD
SO15	80%	96%	NPD	NPD	NPD	NPD
SO16	80%	96%	NPD	NPD	NPD	NPD
SO17	80%	96%	NPD	NPD	NPD	NPD
SO18	80%	96%	NPD	NPD	NPD	NPD
NO01	80%	96%	NPD	NPD	NPD	NPD
NO02	80%	96%	NPD	NPD	NPD	NPD
NO03	80%	96%	NPD	NPD	NPD	NPD
NO04	80%	96%	NPD	NPD	NPD	NPD
NO05	80%	96%	NPD	NPD	NPD	NPD
NO06	80%	96%	NPD	NPD	NPD	NPD
NO07	80%	96%	NPD	NPD	NPD	NPD
NO08	80%	96%	NPD	NPD	NPD	NPD
NO09	80%	96%	NPD	NPD	NPD	NPD
NO10	80%	96%	NPD	NPD	NPD	NPD
NO11	80%	96%	NPD	NPD	NPD	NPD
NO12	80%	96%	NPD	NPD	NPD	NPD
SV01	80%	96%	NPD	NPD	NPD	NPD
SV02	80%	96%	NPD	NPD	NPD	NPD
SV05	80%	96%	NPD	NPD	NPD	NPD
SV06	80%	96%	NPD	NPD	NPD	NPD
SV09	80%	96%	NPD	NPD	NPD	NPD
SV10	80%	96%	NPD	NPD	NPD	NPD
SV13	80%	96%	NPD	NPD	NPD	NPD
SV14	80%	96%	NPD	NPD	NPD	NPD
SV17	80%	96%	NPD	NPD	NPD	NPD
SV18	80%	96%	NPD	NPD	NPD	NPD
SV21	80%	96%	NPD	NPD	NPD	NPD
SV22	80%	96%	NPD	NPD	NPD	NPD

5.3.2. Regulations

Window ID	Orientation	Type	Window Dimensions			Weight
			Height [m]	Width [m]	Overall Thickness [mm]	[kg/m^2]
SO01	SE	Double IG	2845	1630	31	37.5
SO02	SE	Double IG	2845	1630	31	37.5
SO03	SE	Double IG	2845	1630	31	37.5
SO04	SE	Double IG	2230	1660	31	37.5
SO05	SE	Double IG	2230	1660	31	37.5
SO06	SE	Double IG	2230	1660	31	37.5
SO7	SE	Double IG	2230	1660	31	37.5
SO8	SE	Double IG	2230	1660	31	37.5
SO9	SE	Double IG	2230	1660	31	37.5
SO10	SE	Double IG	2230	1660	31	37.5
SO11	SE	Double IG	2230	1660	31	37.5
SO12	SE	Double IG	2230	1660	31	37.5
SO13	SE	Double IG	2230	1660	31	37.5
SO14	SE	Double IG	2230	1660	31	37.5
SO15	SE	Double IG	2230	1660	31	37.5
SO16	SE	Double IG	2230	1660	31	37.5
SO17	SE	Double IG	2230	1660	31	37.5
SO18	SE	Double IG	2230	1660	31	37.5
NO01	NE	Double IG	2870	1555	31	37.5
NO02	NE	Double IG	2870	1555	31	37.5
NO03	NE	Double IG	2230	1555	31	37.5
NO04	NE	Double IG	2230	1555	31	37.5
NO05	NE	Double IG	2230	1555	31	37.5
NO06	NE	Double IG	2230	1555	31	37.5
NO07	NE	Double IG	2230	1555	31	37.5
NO08	NE	Double IG	2230	1555	31	37.5
NO09	NE	Double IG	2230	1555	31	37.5
NO10	NE	Double IG	2230	1555	31	37.5
NO11	NE	Double IG	2230	1555	31	37.5
NO12	NE	Double IG	2230	1555	31	37.5
SV01	SV	Double IG	2870	1555	31	37.5
SV02	SV	Double IG	2870	1555	31	37.5
SV05	SV	Double IG	2230	1555	31	37.5
SV06	SV	Double IG	2230	1555	31	37.5
SV09	SV	Double IG	2230	1555	31	37.5
SV10	SV	Double IG	2230	1555	31	37.5
SV13	SV	Double IG	2230	1555	31	37.5
SV14	SV	Double IG	2230	1555	31	37.5
SV17	SV	Double IG	2230	1555	31	37.5
SV18	SV	Double IG	2230	1555	31	37.5
SV21	SV	Double IG	2230	1555	31	37.5
SV22	SV	Double IG	2230	1555	31	37.5

Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]
SO01	1.1	1 – 1.4		59-72%
SO02	1.1	1 - 1.4		59-72%
SO03	1.1	1 - 1.4		59-72%
SO04	1.1	1 - 1.4		59-72%
SO05	1.1	1 - 1.4		59-72%
SO06	1.1	1 - 1.4		59-72%
SO7	1.1	1 - 1.4		59-72%
SO8	1.1	1 - 1.4		59-72%
SO9	1.1	1 - 1.4		59-72%
SO10	1.1	1 - 1.4		59-72%
SO11	1.1	1 - 1.4		59-72%
SO12	1.1	1 - 1.4		59-72%
SO13	1.1	1 - 1.4		59-72%
SO14	1.1	1 - 1.4		59-72%
SO15	1.1	1 - 1.4		59-72%
SO16	1.1	1 - 1.4		59-72%
SO17	1.1	1 - 1.4		59-72%
SO18	1.1	1 - 1.4		59-72%
NO01	1.1	1 - 1.4		59-72%
NO02	1.1	1 - 1.4		59-72%
NO03	1.1	1 - 1.4		59-72%
NO04	1.1	1 - 1.4		59-72%
NO05	1.1	1 - 1.4		59-72%
NO06	1.1	1 - 1.4		59-72%
NO07	1.1	1 - 1.4		59-72%
NO08	1.1	1 - 1.4		59-72%
NO09	1.1	1 - 1.4		59-72%
NO10	1.1	1 - 1.4		59-72%
NO11	1.1	1 - 1.4		59-72%
NO12	1.1	1 - 1.4		59-72%
SV01	1.1	1 - 1.4		59-72%
SV02	1.1	1 - 1.4		59-72%
SV05	1.1	1 - 1.4		59-72%
SV06	1.1	1 - 1.4		59-72%
SV09	1.1	1 - 1.4		59-72%
SV10	1.1	1 - 1.4		59-72%
SV13	1.1	1 - 1.4		59-72%
SV14	1.1	1 - 1.4		59-72%
SV17	1.1	1 - 1.4		59-72%
SV18	1.1	1 - 1.4		59-72%
SV21	1.1	1 - 1.4		59-72%
SV22	1.1	1 - 1.4		59-72%

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection		
				E	EW	EI
SO01	80%	96%	NPD	NPD	NPD	NPD
SO02	80%	96%	NPD	NPD	NPD	NPD
SO03	80%	96%	NPD	NPD	NPD	NPD
SO04	80%	96%	NPD	NPD	NPD	NPD
SO05	80%	96%	NPD	NPD	NPD	NPD
SO06	80%	96%	NPD	NPD	NPD	NPD
SO7	80%	96%	NPD	NPD	NPD	NPD
SO8	80%	96%	NPD	NPD	NPD	NPD
SO9	80%	96%	NPD	NPD	NPD	NPD
SO10	80%	96%	NPD	NPD	NPD	NPD
SO11	80%	96%	NPD	NPD	NPD	NPD
SO12	80%	96%	NPD	NPD	NPD	NPD
SO13	80%	96%	NPD	NPD	NPD	NPD
SO14	80%	96%	NPD	NPD	NPD	NPD
SO15	80%	96%	NPD	NPD	NPD	NPD
SO16	80%	96%	NPD	NPD	NPD	NPD
SO17	80%	96%	NPD	NPD	NPD	NPD
SO18	80%	96%	NPD	NPD	NPD	NPD
NO01	80%	96%	NPD	NPD	NPD	NPD
NO02	80%	96%	NPD	NPD	NPD	NPD
NO03	80%	96%	NPD	NPD	NPD	NPD
NO04	80%	96%	NPD	NPD	NPD	NPD
NO05	80%	96%	NPD	NPD	NPD	NPD
NO06	80%	96%	NPD	NPD	NPD	NPD
NO07	80%	96%	NPD	NPD	NPD	NPD
NO08	80%	96%	NPD	NPD	NPD	NPD
NO09	80%	96%	NPD	NPD	NPD	NPD
NO10	80%	96%	NPD	NPD	NPD	NPD
NO11	80%	96%	NPD	NPD	NPD	NPD
NO12	80%	96%	NPD	NPD	NPD	NPD
SV01	80%	96%	NPD	NPD	NPD	NPD
SV02	80%	96%	NPD	NPD	NPD	NPD
SV05	80%	96%	NPD	NPD	NPD	NPD
SV06	80%	96%	NPD	NPD	NPD	NPD
SV09	80%	96%	NPD	NPD	NPD	NPD
SV10	80%	96%	NPD	NPD	NPD	NPD
SV13	80%	96%	NPD	NPD	NPD	NPD
SV14	80%	96%	NPD	NPD	NPD	NPD
SV17	80%	96%	NPD	NPD	NPD	NPD
SV18	80%	96%	NPD	NPD	NPD	NPD
SV21	80%	96%	NPD	NPD	NPD	NPD
SV22	80%	96%	NPD	NPD	NPD	NPD

5.3.3. Expected case

Window ID	Orientation	Window Dimensions			Weight [kg/m^2]
		Height [m]	Width [m]	Overall Thickness [mm]	
SO01	SE	2845	1630	58	
SO02	SE	2845	1630	58	
SO03	SE	2845	1630	58	
SO04	SE	2230	1660	58	
SO05	SE	2230	1660	58	
SO06	SE	2230	1660	58	
SO7	SE	2230	1660	58	
SO8	SE	2230	1660	58	
SO9	SE	2230	1660	58	
SO10	SE	2230	1660	58	
SO11	SE	2230	1660	58	
SO12	SE	2230	1660	58	
SO13	SE	2230	1660	58	
SO14	SE	2230	1660	58	
SO15	SE	2230	1660	58	
SO16	SE	2230	1660	58	
SO17	SE	2230	1660	58	
SO18	SE	2230	1660	58	
NO01	NE	2870	1555	58	
NO02	NE	2870	1555	58	
NO03	NE	2230	1555	58	
NO04	NE	2230	1555	58	
NO05	NE	2230	1555	58	
NO06	NE	2230	1555	58	
NO07	NE	2230	1555	58	
NO08	NE	2230	1555	58	
NO09	NE	2230	1555	58	
NO10	NE	2230	1555	58	
NO11	NE	2230	1555	58	
NO12	NE	2230	1555	58	
SV01	SV	2870	1555	58	
SV02	SV	2870	1555	58	
SV05	SV	2230	1555	58	
SV06	SV	2230	1555	58	
SV09	SV	2230	1555	58	
SV10	SV	2230	1555	58	
SV13	SV	2230	1555	58	
SV14	SV	2230	1555	58	
SV17	SV	2230	1555	58	
SV18	SV	2230	1555	58	
SV21	SV	2230	1555	58	
SV22	SV	2230	1555	58	

Window ID	U_g [W/m²K]	U_f [W/m²K]	U_w [W/m²K]	g-value [-]
SO01	0.57	1 – 1.4		35-10%
SO02	0.57	1 - 1.4		35-10%
SO03	0.57	1 - 1.4		35-10%
SO04	0.57	1 - 1.4		35-10%
SO05	0.57	1 - 1.4		35-10%
SO06	0.57	1 - 1.4		35-10%
SO7	0.57	1 - 1.4		35-10%
SO8	0.57	1 - 1.4		35-10%
SO9	0.57	1 - 1.4		35-10%
SO10	0.57	1 - 1.4		35-10%
SO11	0.57	1 - 1.4		35-10%
SO12	0.57	1 - 1.4		35-10%
SO13	0.57	1 - 1.4		35-10%
SO14	0.57	1 - 1.4		35-10%
SO15	0.57	1 - 1.4		35-10%
SO16	0.57	1 - 1.4		35-10%
SO17	0.57	1 - 1.4		35-10%
SO18	0.57	1 - 1.4		35-10%
NO01	0.57	1 - 1.4		35-10%
NO02	0.57	1 - 1.4		35-10%
NO03	0.57	1 - 1.4		35-10%
NO04	0.57	1 - 1.4		35-10%
NO05	0.57	1 - 1.4		35-10%
NO06	0.57	1 - 1.4		35-10%
NO07	0.57	1 - 1.4		35-10%
NO08	0.57	1 - 1.4		35-10%
NO09	0.57	1 - 1.4		35-10%
NO10	0.57	1 - 1.4		35-10%
NO11	0.57	1 - 1.4		35-10%
NO12	0.57	1 - 1.4		35-10%
SV01	0.57	1 - 1.4		35-10%
SV02	0.57	1 - 1.4		35-10%
SV05	0.57	1 - 1.4		35-10%
SV06	0.57	1 - 1.4		35-10%
SV09	0.57	1 - 1.4		35-10%
SV10	0.57	1 - 1.4		35-10%
SV13	0.57	1 - 1.4		35-10%
SV14	0.57	1 - 1.4		35-10%
SV17	0.57	1 - 1.4		35-10%
SV18	0.57	1 - 1.4		35-10%
SV21	0.57	1 - 1.4		35-10%
SV22	0.57	1 - 1.4		35-10%

Window ID	τ_{vis} [R_a]	R_a	Haze	Fire Protection			Air Permeability class
				E	EW	EI	
SO01	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO02	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO03	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO04	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO05	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO06	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO7	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO8	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO9	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO10	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO11	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO12	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO13	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO14	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO15	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO16	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO17	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SO18	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO01	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO02	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO03	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO04	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO05	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO06	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO07	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO08	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO09	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO10	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO11	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
NO12	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV01	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV02	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV05	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV06	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV09	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV10	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV13	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV14	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV17	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV18	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV21	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)
SV22	80%	93-86 %	NPD	NPD	NPD	NPD	SAPA 4150 (A4)

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