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Energy performance of buildings in Portugal and application of the cost-optimal methodology

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Energy Performance Buildings Directive - EPBD

- The European Union has set **energy efficiency targets for buildings**, namely in its Directive 2010/31/EU (Energy Performance Buildings Directive - EPBD) which was updated through the amendment published in directive 844/2018.

- According to article 3, Member States (MS) shall apply a **methodology for calculating the energy performance of buildings** in accordance with the common general framework expressed in the Annex 1.

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Common general framework for the calculation of energy performance of buildings (referred to in Article 3)

- The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall **reflect the heating energy needs and cooling energy needs** (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.
- The energy performance of a building shall be expressed in a transparent manner and shall **include an energy performance indicator and a numeric indicator of primary energy use**, based on **primary energy factors per energy carrier**, which may be based on national or regional annual weighted averages or a specific value for on- site production.
- The methodology for calculating the energy performance of buildings should take into account European standards and shall be consistent with relevant Union legislation, including Directive 2009/28/EC.
- The methodology shall be laid down taking into consideration at least the aspects enumerated in Annex I, point 3 of directive 2010/31/EU.

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Methodology for evaluating Buildings

In Portugal the methodology for evaluation uses a **twin building feature**, which consists of defining a building whose shape and dimensions are equal to the real building under evaluation, with reference solutions like for instance the following building elements and systems:

- Envelop:
  - Maximum “U values” for walls, roofs and floors, and windows;
  - Maximum values for “Solar Heat Gain Coefficient” (SHGC), for both window and blinds;
- Ventilation:
  - Minimum ventilation rates of spaces to ensure air quality;
- Artificial light (only for non-residential):
  - Maximum power densities for Artificial Light;
- Energy Systems:
  - Values for COP and EER of the energy systems for the twin building (Reference Building);

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EPBD and Cost-Optimal - articles 4 and 5 Minimum energy performance requirements

- According to **article 4** MS shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving **cost-optimal levels.** The energy performance shall be calculated in accordance with the methodology referred to in Article 3. Cost-optimal levels shall be calculated in accordance with the comparative **methodology framework referred to in Article 5** once the framework is in place.

- According to **article 5** MS shall calculate cost-optimal levels of **minimum energy performance requirements** using a comparative methodology framework and relevant parameters, such as climatic conditions and the practical accessibility of energy infrastructure, and compare the results of this calculation with the minimum energy performance requirements in force.

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Cost-Optimal Methodology – Delegated Regulation (EU) no. 244/2012

- COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012

- supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

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Cost-Optimal Calculations

Financial calculation

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right]$$

Macro-Economic calculation

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) R_d(i) + C_{c,i}(j)) - V_{f,\tau}(j) \right]$$

Where:

- τ, means the calculation period;
- $C_{g(\tau)}$, means global cost (referred to starting year τ_0) over the calculation period
- *J*, means adopted measure;
- C_I, means initial investment costs for measure or set of measures j *;*
- $C_{a,i}(j)$, means annual costs for measure or set of measures *j* during year i *;*
- $C_{c,i}(j)$, means annual carbon costs for measure or set of measures *j* during year i *;*
- $V_{f,\tau}(j)$, means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0);
- $R_d(i)$, means discount factor for year i based on discount rate *r* to be calculated as:

$$R_d(p) = \left(\frac{1}{1 + r/100} \right)^p$$

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Amendement in directive 844/2018

- Additionally, the amendment published in directive 844/2018 establishes in **Article 2a)** that:

- Each Member State (MS) must establish a long-term renovation strategy to support the renovation of the national park of residential and non-residential buildings, public and private, in a highly energy-efficient **and decarbonised building stock by 2050**, facilitating the cost-effective transformation of existing buildings into near **Zero Energy Buildings (nZEB).**

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Long-Term Strategy for the Renovation

- The Long-Term Strategy for the Renovation of Buildings (LTSR) has been already published for public consultation, pending the publication of the final version. It evaluates the energy performance of the Building Stock and identifies measures - to increase energy and financial efficiency - necessary to achieve the goal of a nearly zero energy building stock.

- This is a very challenging and ambitious objective given that currently 2/3 of the park (which is equivalent to 3.8 million buildings) is not yet covered by any intervention. That occurs because that percentage of the building stock corresponds to buildings constructed before 1990, the year of the first Regulation of energy performance of buildings.

https://participa.pt/pt/consulta/elpre-estrategia-de-longo-prazo-para-a-renovacao-dos-edificios
(acedido em 13-09-2020)

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EPBD article 9 - nearly Zero-Energy Buildings

…

- (2.) Member States shall furthermore, following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings,

….

- (3.) The national plans shall include, inter alia, the following elements:
  - (a) the Member State's detailed application in practice of the definition of nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator of primary energy use expressed in kWh/m^2 per year;

…

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nZEB for Portugal

(nZEB must be beyond Cost-Optmal)

- Ordinance 98/2019, April 2nd was published in order to set nZEB national definition for **residential buildings:**
  - Buildings shall have energy class "A" or higher and 50% of the energy consumed for air conditioning or domestic hot water shall be produced by renewable sources;
- Ordinance 42/2019, January 30th was published in order to set nZEB national definition for **non-residential buildings:**

Context	Requirement	
Near Zero Energy Building	$IEE_S \leq 75\%\ IEE_{S,Ref}$	$R_{IEE} \leq 0.50$
New buildings (not included in nZEB definition)	$IEE_S \leq 100\%\ IEE_{S,Ref}$	$R_{IEE} \leq 1.00$
Major renovations	-	$R_{IEE} \leq 1.50$

Where:

$$R_{IEE} = \frac{IEE_S - IEE_{REN}}{IEE_{ref,S}}$$

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Four pillars for Energy Efficiency

- Methodology for building evaluation based in European and International Standards;
- Requirements of building performance designed for each MS according to the **Cost-optimal** methodology;
- nZEB definition – the goal to be achieved;
- Long-Term Strategy for Renovation (LTSR) – how to achieve that goal:
  - Understand current situation;
  - Funding;
- **Cost-Optimal studies and Results**

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Cost-Optimal solutions vs nZEB

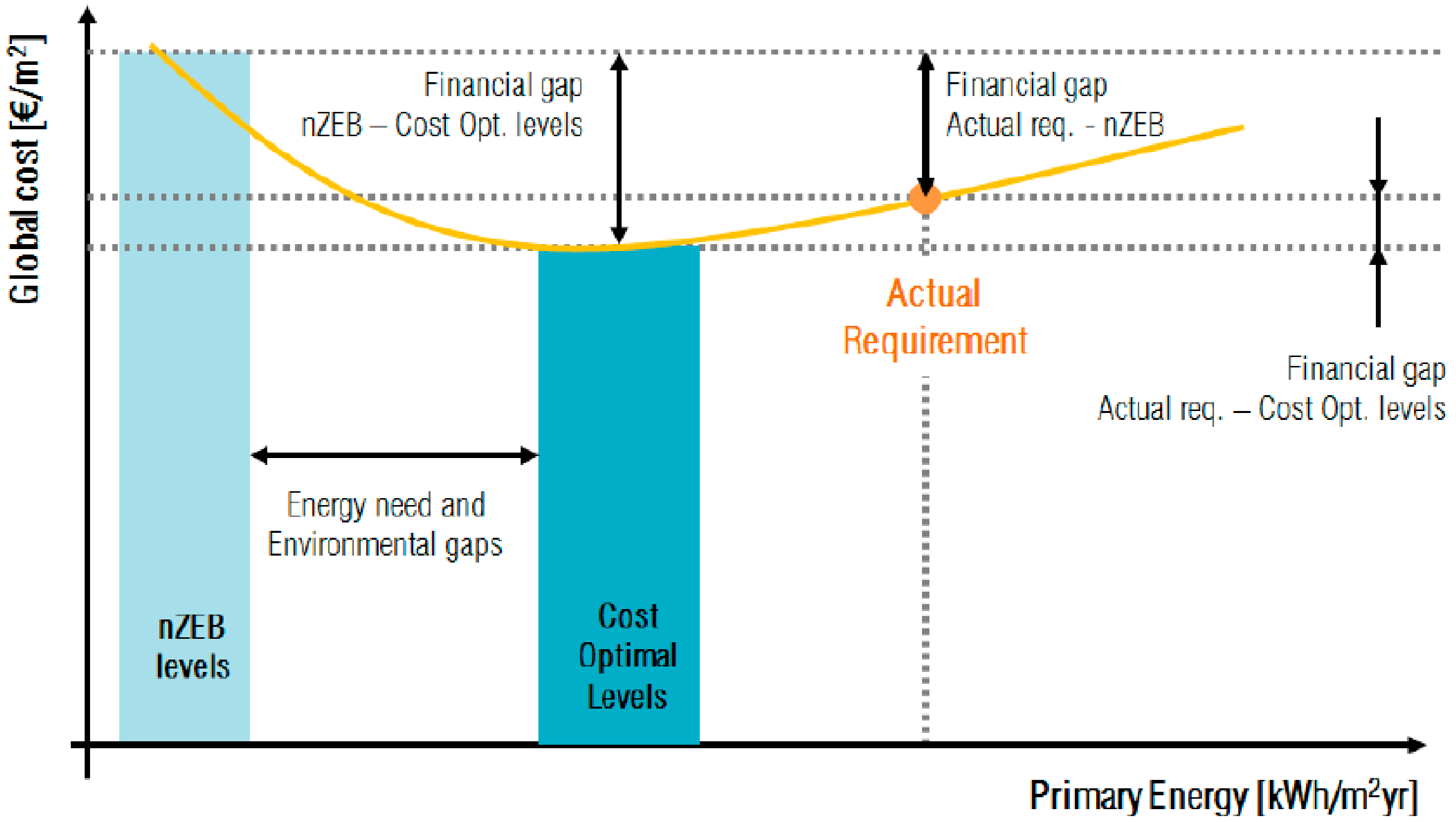

Image obtained from: Maria Ferrara, Valentina Monetti and Enrico Fabrizio, "Cost-Optimal Analysis for Nearly Zero Energy Buildings Design and Optimization: A Critical Review", 2018.

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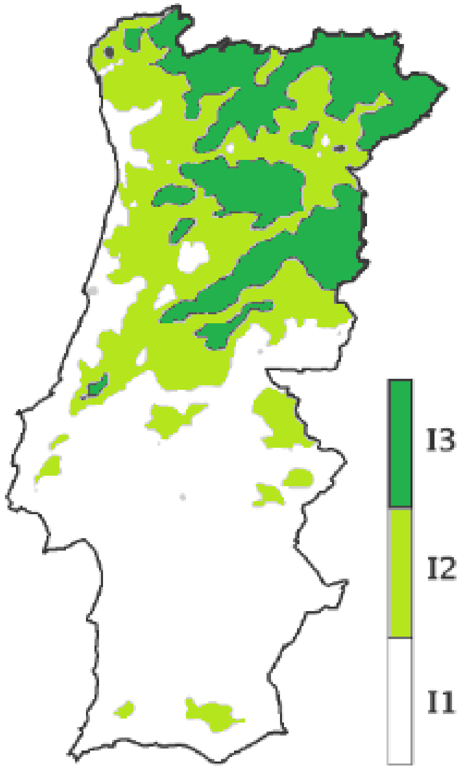
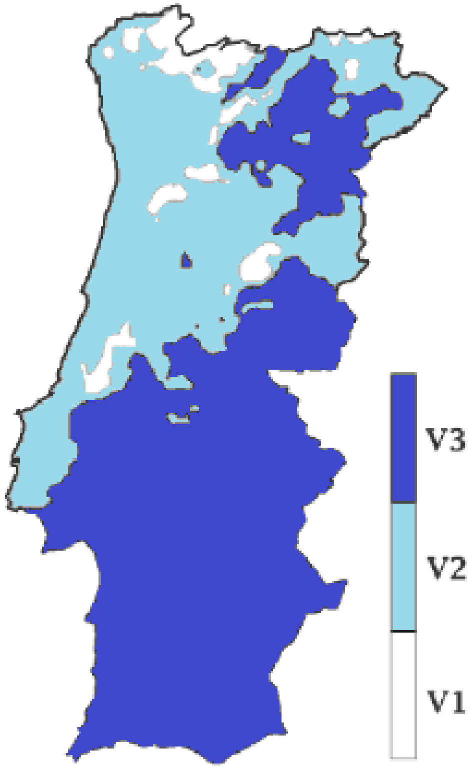
Climate Characterization

Winter



(a)

Summer



(b)

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Examples of Performance Requirements (envelop)

Non-Residential	Climatic Zone			Residential	Climatic Zone		
Portugal - Continent	**Maximal U values (W/m².K)**			**Portugal - Continent**	**Maximal U values (W/m².K)**		
Current Zone of the envelop	**I1**	**I2**	**I3**	Current Zone of the envelop	**I1**	**I2**	**I3**
Vertical opaque exterior and interior envelop	0.70	0.60	0.50	Vertical opaque exterior envelop	0.50	0.40	0.30
Horizontal opaque exterior and interior envelop	0.50	0.45	0.40	Horizontal opaque exterior envelop	0.40	0.35	0.30
Exterior windows and blinds	4.30	3.30	3.30	Exterior windows and blinds	2.80	2.40	2.20
Autonomic regions [Islands of Azores and Madeira]				**Autonomous regions [Islands of Azores and Madeira]**			
Current Zone of the envelop	**I1**	**I2**	**I3**	Current Zone of the envelop	**I1**	**I2**	**I3**
Vertical opaque exterior and interior envelop	1.40	0.90	0.50	Vertical opaque exterior envelop	0,70	0,60	0,45
Horizontal opaque exterior and interior envelop	0.80	0.60	0.40	Horizontal opaque exterior envelop	0,45	0,40	0,35
Exterior windows and blinds	4.30	3.30	3.30	Exterior windows and blinds	2.80	2.40	2.20

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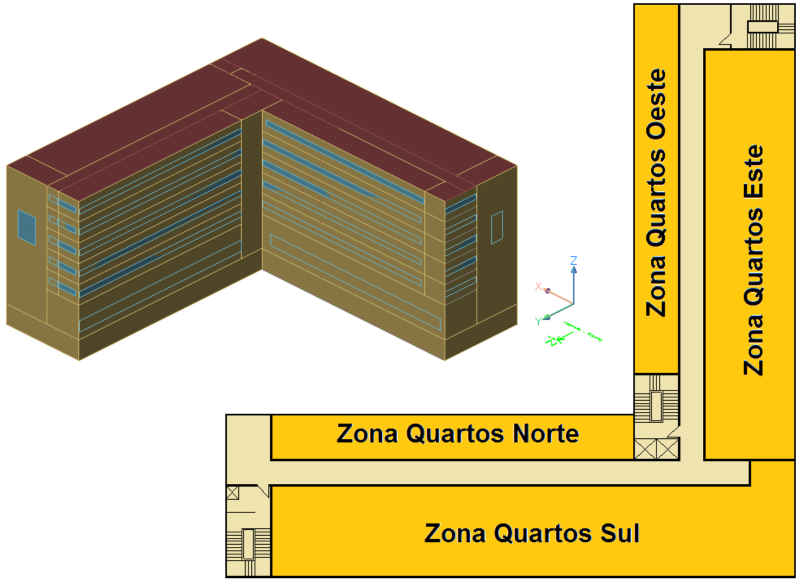
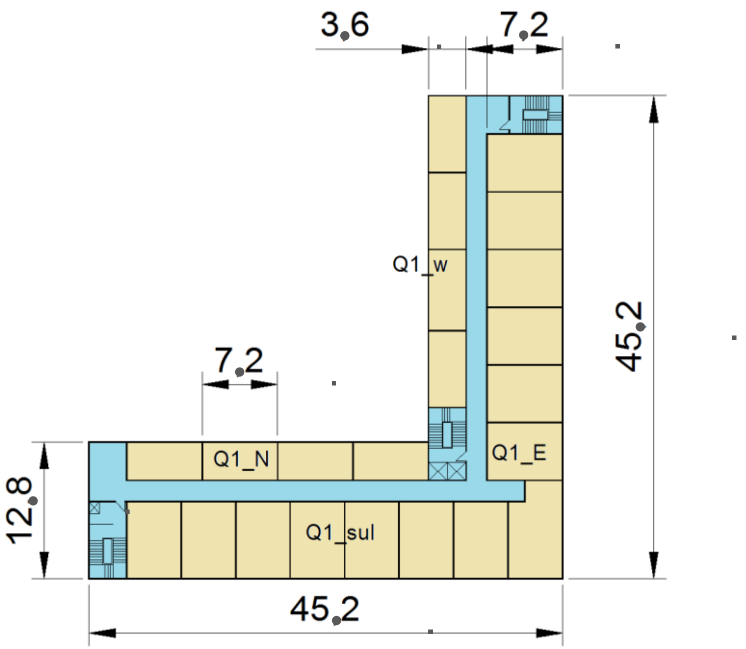
Example of application of this methodology (hotels)

- A typical building is defined – dimensions express mean values of available examples of that type of building;
- Different types of measures, were combined holistically.





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Some measures holistically evaluated

Types of Walls

ID	Thickess of insulation (cm)	U-Value (W/m²K)	Initial Cost (€/m²)	Life time (years)	Maintenance (€/m²)	Time gap Mainten. (years)	Global Cost (€/m²)
REF I1	3.4	0.70	96,00	30	6.00	10	102.60
REF I2	4.2	0.60	98,00	30	6.00	10	104.60
REF I3	5.8	0.50	100,00	30	6.00	10	106.60
P00	0	1.30	90,00	30	6.00	10	96.60
P04	4	0.58	98,00	30	6.00	10	104.60
P06	6	0.45	102,00	30	6.00	10	108.60
P08	8	0.37	106,00	30	6.00	10	112.60
P10	10	0.31	110,00	30	6.00	10	116.60
P12	12	0.27	112,00	30	6.00	10	118.60

Types of Roofs

ID	Thickess of insulation (cm)	U-Value (W/m²K)	Initial Cost (€/m²)	Life time (years)	Maintenance (€/m²)	Time gap Mainten. (years)	Global Cost (€/m²)
REF I1	5.7	0.50	60.00	30	16.00	10	77.70
REF I2	6.5	0.45	62.50	30	16.00	10	80.70
REF I3	8.0	0.40	65.00	30	16.00	10	82.70
C06	6	0.67	62.00	30	16.00	10	79.70
C10	10	0.41	68.00	30	16.00	10	85.70
C12	12	0.34	74.00	30	16.00	10	91.70
C15	15	0.27	82.00	30	16.00	10	99.70

Artificial lights

	Artificial Light			Total for rooms		Ajusted power density	
Zone	Luminous flux (lúmen)	Power (W)	Número	Luminous flux (lúmen)	Power (W)	W/m²	(W/m²) /100 lux
Bedrooms	3 350	28	6	20 100	168	5.6 Ref: 8.8	1.7 Ref: 3.8
Circulations	1 500	12.5	10	15 000	125	1.6 Ref: 3.01	1.60 Ref: 3.4

Types of windows

ID	Frame material	Glass	U value W/m²K	Initial Cost (€/m²)	Life time (years)	Maintenance (€/m²)	Time gap Mainten. (years)	Global Costo (€/m²)
REF I1	Al [4]	Double transparent	4.30	570	35	50	10	560
REF I2	Al [4]	Double transparent	3.30	575	35	50	10	564
REF I3	Al [4]	Double transparent	3.00	580	35	50	10	568
V1	PVC	Single colored	1.50	642	35	50	10	638
V2	Al (sct)	Double transparent	1.10	570	35	50	10	577
V3	PVC	Single colored	2.20	662	35	50	10	656
V4	Al	Double colored	3.40	590	35	50	10	594

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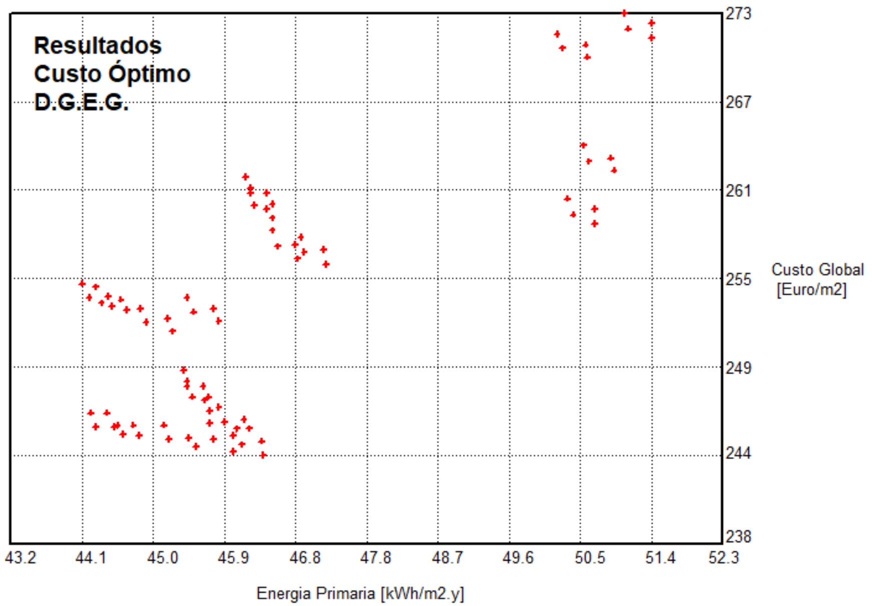
Cost-optimal results for hotels

- Computer Simulations with “energy plus” program have been performed for every package of solutions and for every climate under consideration;
- Interface Software written in PROLOG is used, automatically generates holistic files for simulation combining the different packages and collect results as well.



Climate Region	Configuration	Wall insulation (cm)	Roof insulation (cm)	U-Value Windows (W/m²K)	COP HVAC	EER HVAC
I3 V1 (Guarda)	Reference	5.8	8.0	3.0	3.00	2.90
	Cost-Optimal	6.0	12.0	1.1	4.15	3.74
I2 V2 (Barcelos)	Reference	4.2	6.5	3.3	3.00	2.90
	Cost-optimal	4.0	6.0	1.1	4.15	3.74
I1 V2 (Lisboa)	Reference	3.4	5.7	4.3	3.00	2.90
	Cost-Optimal	6.0	6.0	3.4	4.15	3.74
I1 V3 (Évora)	Reference	3.4	5.7	4.3	3.00	2.90
	Cost-Optimal	6.0	6.0	3.4	4.15	3.74

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Residential Buildings – Apartments

Number of floors			5	
Medium floor height			2.7	m
Floor useful area			130.0	m²
Floor in contact with another apartment in lower floor (intermediate apartment)			130.0	m²
Roof in contact with another apartment in upper floor (intermediate apartment)			130.0	m²
Horizontal exterior opaque Envelop	Roof in contact with Exterior (last floor)		130.0	m²
Vertical exterior opaque Envelop	South Wall		19.9	m²
	North Wall		22.9	m²
	West Wall		4.7	m²
	Plan Thermal Bridge South	Structure	4.9	m²
		Shading device	1.6	m²
	Plan Thermal Bridge North	Structure	4.9	m²
		Shading device	1.6	m²
	Plan Thermal Bridge West	Structure	1.4	m²
		Shading device	0.3	m²
linear Thermal Bridges	Connection between intermediate floors		52.0	m
	Connection between window frames and facades		37.8	m
	Connection between window frames and shading device boxes		4.4	m
	Connection between vertical walls		2.7	m
	Connection between facades and balconies		4.2	m
Transparent exterior envelope (glazzings)	North		5.3	m²
	South		8.4	m²
	West		1.6	m²

Geometrical definitions for a typical building or mean Building

Interior Envelop

Spaces without HVAC	Volume (m³)	Wall área of the apartment (m²)	B_{Tr}	Space areas in contact with exterior (m²)	Area in contact with other apartments (m²)
Stairs	427.2	43.8	0.3	116.7	105.1
Adjacent Building	-	26.7	0.6	-	-
Entry zone	40.0	13.4	0.4	0.0	13.4
Lifts	73.0	5.3	0.3	36.5	62.4

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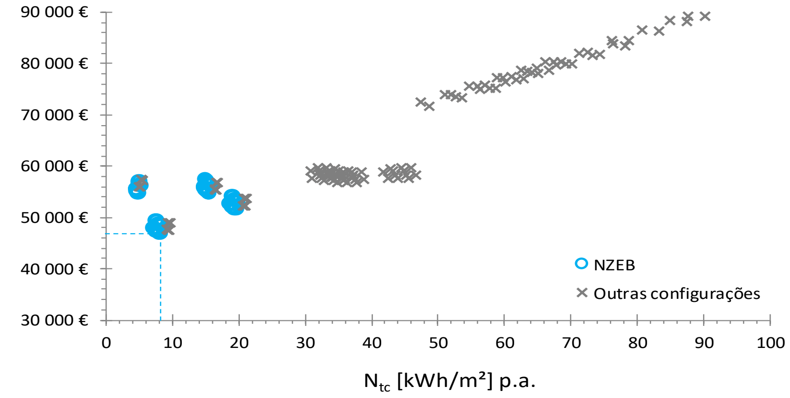
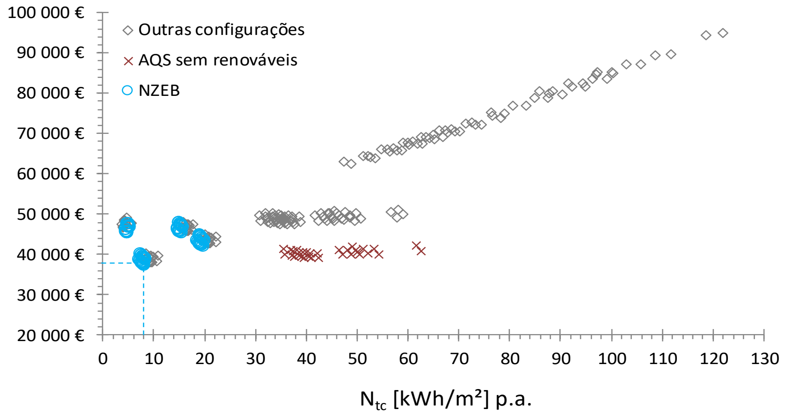
Residential Apartments - Results



New apartments (climate I_2-V_2)



Existing apartments (Climate I_2-V_2)

Residential apartments – New Buildings

Climate Region	Insulation		windows		Heating and cooling systems	DHW system	N_{tc} [kWh/m² p.a.]	RER	Class e	NZEB
	Walls and thermal bridges	Roofs	Window frames	Shading devices						
I1 V2	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	6	86%	A+	Yes
I1 V3	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	8	83%	A+	Yes
I2 V2	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	8	82%	A+	Yes
I2 V3	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	12	80%	A+	Yes
I3 V2	6 – 10 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	11	79%	A+	yes

Residential apartments – Existing Buildings

Climate Region	Insulation		windows		Heating and cooling systems	DHW system	N_{tc} [kWh/m² p.a.]	RER	Classe	NZEB
	Walls and thermal bridges	Roofs	Window frames	Shading devices						
I1 V2	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	6.2	86%	A+	Yes
I1 V3	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	8.1	83%	A+	Yes
I2 V2	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	8.1	82%	A+	Yes
I2 V3	4 – 6 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	12.4	80%	A+	Yes
I3 V2	6 – 10 cm	10 –12 cm	aluminium	Bright colour	HVAC	Biomass	10.9	79%	A+	yes

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Detached Houses

Existing Detached houses

Climate Region	Insulation thickness for walls and thermal bridges (cm)	Insulation thickness for roofs (cm)	Windows name	Heating System	Cooling System	Domestic Hot Water System
I1 V1	6	6	AI	Biomass	--	Biomass
I3 V1	6	10	AI	Biomass	--	Biomass
I1 V2	3	6	AI	Heat Pump		Biomass
I2 V2	3	6	AI	Heat Pump		Biomass
I3 V2	4	10	AI	Heat Pump		Biomass
I1 V3	3	6	AI	Heat Pump		Biomass
I2 V3	3	6	AI	Heat Pump		Biomass

Performance requirements for Residential Buildings have shown that their values are close to those imposed by regulations

New Detached houses

Climate Region	Insulation thickness for walls and thermal bridges	Insulation thickness for roofs	Windows name
I1 V2	6 cm	6 cm	2
I1 V3	4 cm	6 cm	2
I2 V2	4 cm	10 cm	1b
I3 V1	10 cm	10 cm	2
I3 V2	10 cm	10 cm	2

Climate Region	Heating System	Cooling System	DHW
I1 V2	HVAC	HVAC	Solar thermal
I1 V3	HVAC	HVAC	Solar termal
I2 V2	Biomass (with/DHW)	--	Biomass (with/DHW)
I3 V1	Biomass (with/DHW)	--	Biomass (with/DWH)
I3 V2	HVAC	HVAC	Solar thermal

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Office buildings - Results

Climatic Region	Configuration	Wall insulation (cm)	Roof insulation (cm)	U-value Windows (W/m²K)	COP HVAC	EER HVAC
I3 V1	Reference	3.4	5.7	3.0	3.00	2.90
	Cost-optimal	0.0	6.0	1.1	4.15	3.74
I1 V2	Reference	3.4	5.7	4.3	3.00	2.90
	Cost-optimal	0.0	6.0	1.1	4.15	3.74
I1 V3	Reference	5.8	8.0	4.3	3.00	2.90
	Cost-optimal	0.0	6.0	1.1	4.15	3.74

- Cost – Optimal solutions for walls have no insulation material;
- However, condensations can occur and must be prevented – insulation is needed because of this reason;
- Occupancy schedules have large influence – high number of people inside the building which produces gains and no night occupancy;
- Summer conditions have more energy needs than winter.

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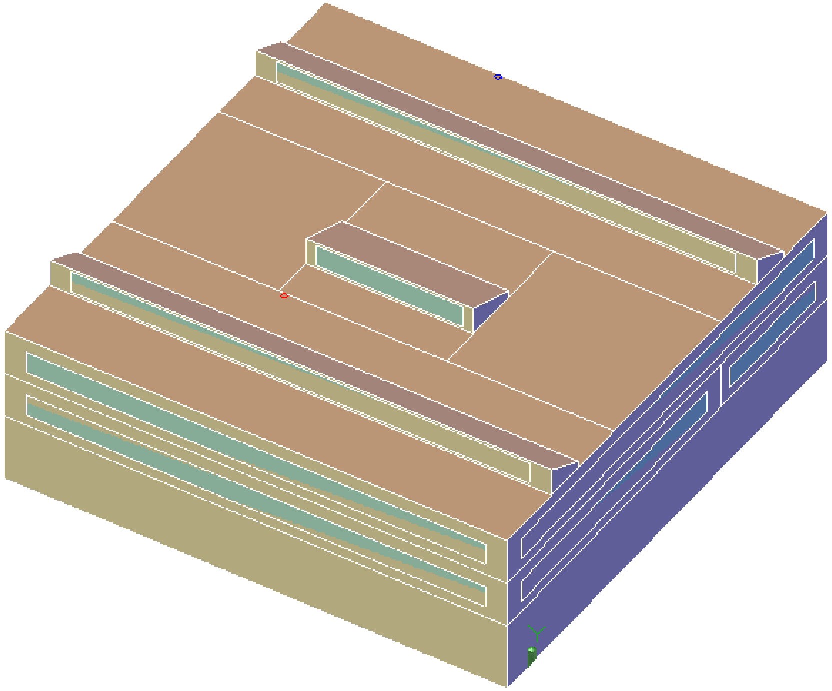
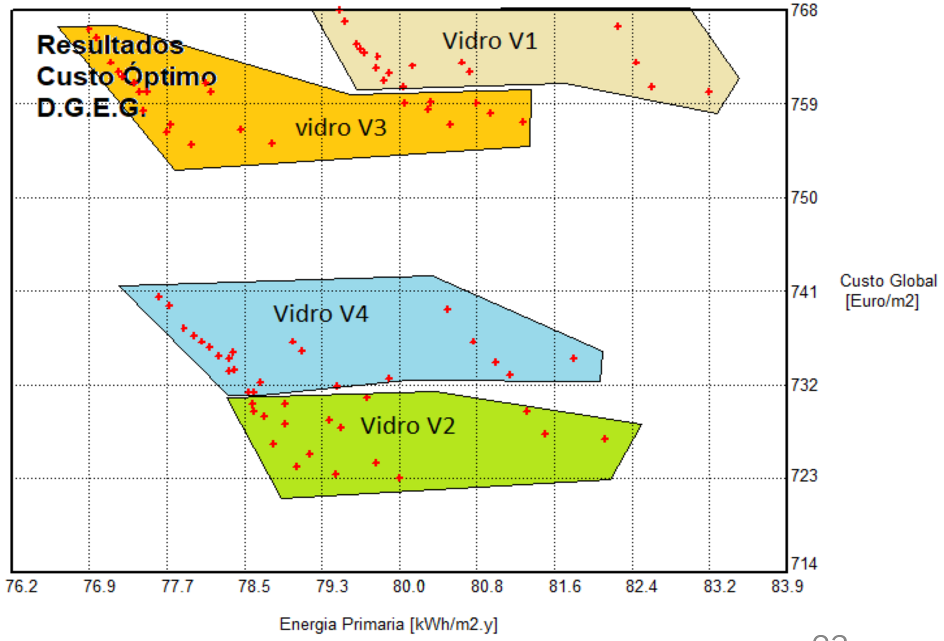
Health care buildings



Zona climática	Configuração	Isolamento nas paredes (cm)	Isolamento na cobertura (cm)	U janelas (W/m²K)	COP AVAC	EER AVAC
I3 V1 (Guarda)	Referência	5.8	8.0	3.0	3.0	2.9
	Custo-ótimo	4.0	6.0	1.1	4.0	3.2
I2 V2 (Barcelos)	Referência	4.2	6.5	3.3	3.0	2.9
	Custo-ótimo	4.0	6.0	3.4	4.0	3.2
I1 V2 (Lisboa)	Referência	3.4	5.7	4.3	3.0	2.9
	Custo-ótimo	4.0	6.0	3.4	4.0	3.2
I1 V3 (Évora)	Referência	3.4	5.7	4.3	3.0	2.9
	Custo-ótimo	4.0	10.0	3.4	4.0	3.2



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Conclusions

- In order to achieve the European goal imposed by the EPBD of having a decarbonized building stock in 2050, existing buildings must be transformed into nZEB;
- Since 2/3 of the building stock was built before 1990 (the year of the 1st Portuguese Energy Code for buildings) the majority of buildings needs energetic refurbishment in order to meet nZEB requirements;
- Different strategies must be applied according to the type of building – Cost Optimal studies highlight the most important strategies and technologies that must be applied to each type of building.

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Thank you for your attention,

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