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CHALLENGES OF NEARLY ZERO ENERGY IN URBAN AREAS FROM PERFORMANCE TO COST - CASE STUDY

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II. Borlin, G., Pinheiro, M. , Condessa, B. (2013). Nearly Zero Energy applied to urban zones – Main challenges and perspectives. Portugal SB13-Contribution of sustainable building for EU 20-20-20 targets. Guimarães, 30 October - 1 November 2013.

ABSTRACT: The introduction of Nearly Zero Energy Building by the Directive 2010/31/EU on energy performance of buildings induces a new paradigm. Buildings do not exclusively belong to the demand side of the energy system anymore; they become a source of electricity generation and thus equally part of the supply side. This new perspective, added to the consideration that nearly zero energy is not yet cost optimal as required by the directive, make wonder the pertinence of enlarging the concept of nearly zero energy to urban scale. The thesis will discuss which would be the technical and economic implications and challenges of this change of scale, firstly considering the advantages concerning building and system factor, the ones to which the current trends are fostered, and then widening the analysis to morphology and transport consumptions, that seem to have the power to further enhance the potentialities of nearly zero energy. Finally, chosen a neighborhood case study in the surrounding of Lisbon, it will be applied the approach to nearly zero energy for refurbishment at urban scale with the aim of quantifying some advantages that urban scale can enhance, and in particular the effect of the economy of scale that the bulky purchase can trigger.

Keywords: Nearly zero energy; Economy of scale; Urban morphology; Energetic refurbishment

RIASSUNTO: Il concetto di edificio a energia quasi zero (Nearly Zero Energy Building), introdotto dalla Direttiva 2010/31/EU sulla prestazione energetica degli edifici, innesca un cambio di paradigma. Gli edifici non sono più considerati solo dal lato della domanda ma diventano altresì una sorgente di energia e quindi ugualmente inclusi nel lato dell'offerta. Questa nuova prospettiva in combinazione al fatto che i requisiti di energia quasi nulla non sono ancora raggiungibili a costo ottimo, nonostante questo sia una condizione richiesta dalla direttiva, fa sorgere il quesito sull'opportunità di estendere l'applicazione del concetto di energia quasi nulla dal singolo edificio alla scala urbana. Obiettivo della prima parte della tesi è individuare e discutere quali sono le implicazioni tecniche ed economiche di questo cambio di scala concentrandosi inizialmente sull'influenza dei fattori edificio e impianto, i due fattori maggiormente studiati, per poi completare la discussione includendo nell'analisi l'impatto di morfologia urbana e consumo dei trasporti, i quali sembrano essere due fattori in grado di potenziare ulteriormente le qualità del concetto di energia quasi nulla. La seconda parte si concentrerà sull'applicazione del concetto di energia quasi nulla ad un quartiere caso di studio nei dintorni di Lisbona che presenti necessità di riabilitazione. L'obiettivo del caso di studio è la quantificazione di alcuni vantaggi che la scala urbana può favorire, e in particolare la quantificazione dell'economia di scala che essa può innescare grazie alla grande quantità di materiale da acquistare.

Parole chiave: Energia quasi zero; Economia di scala; Morfologia urbana; Riabilitazione energerica

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ACRONYMS

AMES: Agência Municipal de Energia de Sintra (Municipal energy agency of Sintra)
BPIE: Buildings Performance Institute Europe
CAGR: Compound Annual Growth Rate
CHP: Combined Heat and Power
DHW: Domestic hot water
EPBD: Energy Performance Building Directive
EPS: Expanded Polystyrene
ETICS: External Thermal Insulation Composite System
EU: European Union
GHG: Greenhouse Gas
H_m: average solar irradiance
kWh/m^2a: kilowatt hours per square meter per annum
KW_p: kilowatt peak
NZEB: Nearly Zero Energy Building
NZEUA: Nearly Zero Energy Urban Area
O&M: Operation and Maintenance
$P_{el,p}$: peak electrical power
RCCTE: Regulamento das Características de Comportamento Térmico dos Edifícios (Regulation about the characteristics of thermal behavior of buildings)
REHVA: Federation of European Heating, Ventilation and Air-conditioning Associations
UHI: Urban Heat Island

1 INTRODUCTION

1.1 MOTIVATIONS AND DIRECTIONS OF THE THESIS

The European Union aims at a drastic reduction in greenhouse gases (GHG) emission, being bound by the Kyoto Protocol to the reduction of such gases by at least 5 per cent below 1990 levels in the period 2008 to 2012 (UN 1998) and targeting to really ambitious commitment for 2020, with "the EU climate and energy package" (EU 2009), and for 2050, with "Roadmap for moving to a competitive low carbon economy in 2050" (EC 2011a).

The EU climate and energy policy sets the following targets for 2020:

- Cutting greenhouse gases by at least 20% of 1990 levels
- Cutting energy consumption by 20% of projected 2020 levels - by improving energy efficiency;
- Increasing use of renewables energies (wind, solar, biomass, etc.) to 20% of total energy production (currently ± 8.5%) (EU 2009).

EU bound itself to even higher commitment to reduce GHG emission to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group (EC 2011a).

Since buildings account for around 40% of total energy consumption and 36% of CO2 emission in Europe (Atanasiu 2011), the reduction of energy consumption and the use of energy from renewable sources in the building sector constitute therefore important measures needed to reduce energy dependency and GHG emission. Without consequently exploiting the great potential saving of buildings the EU will miss its reduction targets.

Aware of this huge saving potential, in order to comply with the emission commitments, EU parliament published the Directive 2010/31/EU (EPBD recast) on the energy performance of buildings.

The instrument introduced to fight GHG emission is a new building standard, Nearly Zero Energy Building (NZEB), that is a building that has a very high energy performance which zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, produced on-site or nearby (EU 2010).

NZEB therefore initiates a change of paradigm. Indeed, such building does not exclusively belong anymore to the demand side of the energy system; it becomes a source of electricity generation and thus equally part of the supply side (Koch and Girard 2011).

This new perspective suggests the opportunity of discussing the benefits of enlarging the application of nearly zero energy to urban scale, evolving from the concept of NZEB to Nearly Zero Energy Urban Area (NZEUA), due to the fact that there may be good reasons to address a group of buildings and to have a common energy balance for them.

Concerning for example on site production, urban scale seems to enable alternative strategies not viable at building scale. On-site central systems as an alternative to individual building systems can in fact yield benefits in terms of investment savings, better efficiency and better possibilities for seasonal storage (Atanasiu 2011).

In addition the EPBD recast states that nearly zero energy should be achieved at optimal cost. However it has been verified that nearly zero energy is not yet cost optimal for buildings with current market prices (Kurnitski et al. 2011b).

So the problem is to find a solution that could match the nearly zero energy performance targets and the cost-optimality of its implementation, to guarantee the simultaneous achieving of both the aims of the directive.

The purpose of the thesis is therefore to discuss which could be the technical and economic implications and challenges of nearly zero energy applied at urban scale; and if this scale could be a proper scale to enhance the benefits of nearly zero energy, thus overcoming the current limitations of this concept.

1.2 OBJECTIVES AND METHODOLOGY

The thesis starts from the hypothesis that nearly zero energy at urban scale can be achieved with good performance and cost. So, the objective is to identify what building and urban design strategies must be followed to assure a good balance between costs and nearly zero energy and carbon level. The approach proposed to urban areas will be then applied to a specific case study.

The thesis main methodological steps are: 1) Nearly Zero Energy Building review: from building to urban zone; 2) Challenges of urban zone: state of art review; 3) Application to Case Study: Characteristics, current energy/carbon, cost and performance; 4) Discussion and conclusion about the challenges of nearly zero carbon to buildings and urban zones.

The thesis will start with an overview of the NZEB concept to understand the ambit of its application and purposes, and what, within the definition of NZEB, suggests a change of scale to urban.

Secondly it will be discussed which is the current knowledge about the potentialities, in reducing consumptions and costs, of intervening at urban scale instead than for the single building. It will be proposed a review of the results and considerations of a collection of scientific papers published in last years. Indispensable for this purpose it has been resorting to sources as science direct and the results of researches supported by EU.

Afterwards, with a clearer awareness of the wide range of challenges that urban scale can enable, the approach to nearly zero energy at urban scale will be applied to a case study neighborhood, with the purpose of assessing the effect that the reduction in acquisition price determines in term of feasibility of the investment.

The approach will be applied to refurbishment instead than to new construction. This choice has been taken in the awareness that EU context is highly urbanized, and therefore before occupy new lands should be capitalized on the existing building stock.

Working at urban scale, due to the huge number of building constituting the neighborhood, it will be necessary firstly to proceed to a typification of the building stock, in order to classify the buildings in few typologies, whose buildings are associated by similar consumptions.

Secondly it will be proceed to the estimation of the buildings stock consumptions before and after the intervention. For this purpose it will be resorted to the program Design Builder that, running with Energy Plus, allows a dynamic thermal simulation of buildings. Then it will be conducted, for all the refurbishment solutions proposed, a feasibility study to understand if the application at urban scale is interesting in term of economic upturn.

Finally with the results obtained from the case study and the review of the state of art it will be drawn final remarks about the challenges of nearly zero energy and which are still some open questions that, to be answered, need further study and development in future works.

1.3 STRUCTURE OF THE THESIS

Chapter 1: It gives an introduction to the motivations of the thesis and its purposes.

Chapter 2: This chapter gives an overview to the definition of NZEB and its main challenges and perspectives. The aim of this chapter is to clarify what is the purpose of Directive 2010/31/EU (EPBD recast), and what drove EU to introduce this new standard. Being the subject of the thesis the concept of nearly zero energy applied to urban areas, before entering in detail in the discussion of the implications of urban scale, it is necessary to clarify the concept that is its foundation, nearly zero energy.

This chapter also underlines which are the open questions and main limitations of the concept and the premises that suggest the possibility to benefit from further advantages when its application is conducted at urban scale instead than at the single building.

Chapter 3: It discusses the extension of the application of NZEB to the urban scale and which are the main challenges and perspectives of nearly zero energy applied to the new scale and how it could enhance the achieving of the targets set for NZEB.

Firstly it focuses on the advantages of urban scale when taking into account only building (passive solutions) and system factors (active solutions) that are the factors studied by current trends and later it highlights how, at urban scale, further advantages to the concept of nearly zero energy are introduced when urban morphology, factor 2, is included as a parameter to control consumptions. Urban morphology in fact seems determinant both in determining the building and transport consumption. Factor 2 means that it is potentially able of reducing consumption by 50%.

Finally it analyzes how interesting approaches to low energy developments have been led in some reference sustainable neighborhood. References for this discussion are BedZED, near London, and Vauban, in Freiburg.

Chapter 4: It describes the application of nearly zero energy to a chosen neighborhood case of study. For this neighborhood it proposes a refurbishment strategy at urban scale.

The purpose of this chapter is to quantify the effect of the economy of scale in refurbishment, and to see if the achieving nearly zero energy standards can be economically feasible at urban scale.

After proposing a refurbishment strategy through passive solutions, in order to reduce the current consumption, and chosen active solutions to supply the energy required, it discusses the results obtained, highlighting if nearly zero energy could be economically feasible when applied to urban

Chapter 5: Summing up the considerations attained through the discussion of the challenges of NZEUA (chapter 3) and the results of the analysis of the case study (chapter 4) it draws concluding remarks concerning the potentiality of the application of nearly zero energy to urban areas.

References

Annexes: The annexes present information that integrates the discussion of the dissertation and helps to understand how the results have been obtained. They present the detailed characterization of the neighborhood and the drawings of the building stocks and typification proposed. Furthermore they present the excel tables with the results of the simulations and the quantification of savings due to the refurbishment. Finally they present the tables with the sizing of the photovoltaic and solar thermal and the feasibility study of the solutions proposed.

2 NEARLY ZERO ENERGY BUILDINGS

2.1 DIRECTIVE 2010/31/EU

Buildings account for 40 % of total primary energy consumption and 36% of CO_2 emission in EU (Atanasiu 2011). The sector is expanding, so the related energy consumption is bound to increase. The reduction of energy consumption and the use of energy from renewable sources in the buildings sector therefore constitute important measures needed to reduce the EU energy dependency and GHG emission (EU 2010). Without exploiting the huge saving potential of the building stock, the EU will miss its reduction targets.

Aware of the great influence of building sector the Directive 2010/31/EU (EU 2010), the European reference directive on the energy performance of buildings (EPBD recast), promotes the improvement of the energy performance of buildings within the EU, and introduces a new standard for building, the Nearly Zero Energy Building.

NZEB is therefore introduced as instrument to guarantee the achievement of the strict target of reducing GHG emission to which EU has been bound since its commitments with the Kyoto protocol.

The task expected from the implementation of NZEB is that the reduced energy consumption and increased use of energy from renewable sources advocated would help the EU to honor both its long term commitment to maintain the global temperature rise below 2 °C, and to reduce overall GHG emission by at least 20 % below 1990 levels by 2020 (EU 2010).

NZEB is defined as a building that has a very high energy performance, which nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy produced on-site or nearby (EU 2010, article 2).

The two main focus of NZEB standard are:

- The performance of the building, and
- The cost-optimality of its implementation.

Concerning the performances, the NZEB targets to "very low amount of energy" required to keep the internal comfort condition, thus addressing to the implementation of passive strategies.

NZEB differs from the voluntary standards for highly energy efficient buildings, as passive house, since it is not restricted to reach low consumption. In addition to achieving low consumption it suggests in fact that a "significant extent of energy by renewable sources produced on-site or nearby" should cover the need of the buildings, in order to reduce emission through cleaner sources. It advocates the production on-site or nearby with the purpose of reducing the dependence from the grid.

The NZEB introduces a change of paradigm, building is not seen anymore only on the side of the energy demand, but it also contributes to the supply of energy. The requirements are not fixed anymore in term of consumption, but in term on energy balance. What interests is not the energy consumption itself, but the balance between energy consumed and produced. What has to be guaranteed is not that the buildings consumes less than a maximum consumption allowed, but that the balance between energy consumed and energy produced on-site never exceed the limit sets for NZEB standard (fig.1).

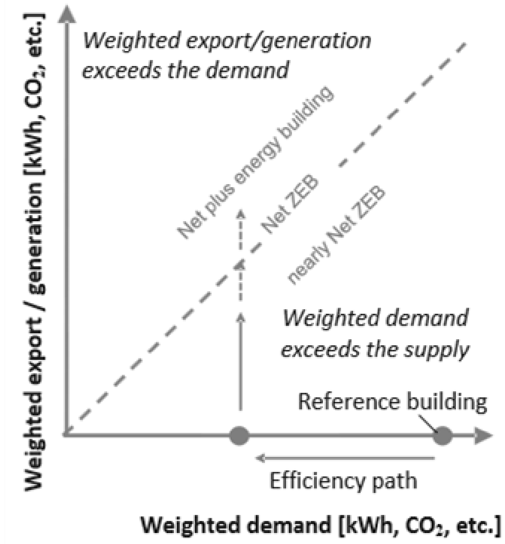


Figure 1: Nearly zero energy concept (Voss, Sartori & Lollini 2012)

What differentiates Nearly Zero Energy Buildings from Net Zero Energy Buildings is that for the latter the balance between energy consumed and produced must be equal to zero, while for Nearly Zero Energy Buildings the balance is near zero but the production does not need to cover the entire energy consumed. This work will focus on the concept of Nearly Zero Energy Buildings being the one which the directive concerns.

The EPBD recast does not focus only on the energy performance of the building, it also underlines the importance of the cost of its implementation, being aware that an extensive implementation is possible only if prices are competitive and that the extensive implementation is necessary to reach the significant GHG reduction expected. For this reason it advocates that minimum energy performance requirements for the buildings should be set “with a view to achieve cost-optimal levels”.

Cost optimal means that energy performance level has to lead to the lowest cost during the estimated economic lifecycle, where the lowest cost is determined taking into account energy related investment costs, maintenance and operating costs, where applicable, and disposal costs, where applicable (EU 2010, article 2).

Cost optimal levels should be set at national level following the comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (EU 2012).

The directive sets the deadline for the full implementation of NZEB by:

- 31 December 2020, for all new buildings, and
- 31 December 2018, for new buildings occupied and owned by public authorities (EU 2010, article 9).

It is task of the state members to draw up national plan for increasing the numbers of NZEB, develop policies and set targets in order to stimulate the transformation of building that are refurbished into NZEB, and detail the definition of NZEB reflecting their national, regional or local condition and including a numerical indicator of primary energy use expressed in kWh/m^2 per year (EU 2010).

To facilitate the application by the member states, the directive gives only a qualitative definition on NZEB, in order to guarantee flexibility. However to this flexibility is associated uncertainty about the actual ambitions. The directive does not prescribe uniform approach for the implementation.

The terms “nearly zero or very low amount of energy” and ”very significant extent by energy from renewable sources” needs for further clarification, so that the implementation done by the member states can be effective in reaching the targets (Atanasiu 2011).

It is therefore necessary to clarify and specify the recommendation of the EPBD recast through a common approach that guarantees univocal interpretation.

Since there is not yet an EU directive that quantifies and specifies the prescriptions of the EPBD recast, in this work it will be followed the Federation of European Heating, Ventilation and Air-conditioning Associations technical definition of the NZEB given by the “REHVA proposal for uniformed national implementation of EPBD recast” (Kurnitski et al 2011a). Moreover some challenges and controversial aspects of the directive will be discussed following the “Principles for Nearly Zero Energy Buildings” (Atanasiu 2011).

2.2 THE TECHNICAL DEFINITION

In order to end up with general definitions, a technical definition is needed to clarify how the energy balance of the building should be calculated, which are the system boundaries, that means which are the energy flows that shall be included in energy performance assessment, and how the primary energy factors should be used for primary energy indicator calculation.

Following the cost-optimality principle of the EPBD recast, NZEB definition is proposed as "the national cost optimal energy use of > 0 kWh/(m²a) of primary energy". The use of > 0 kWh/(m²a) of primary energy should be considered as balance between delivered and exported energy, according to EPBD recast and EN 15603:2008.

The indicator of the energy balance is the net delivered energy, which is delivered minus exported energy per energy carrier (fig. 2). This numeric indicator of primary energy will be used to define the minimum requirement for NZEB.

Figure 2: Net delivered energy (Kurnitski al 2011a)

Primary energy can be calculated as: $E = \sum_i(\mathrm{E}_{\mathrm{del,i}} * \mathrm{f}_{\mathrm{del,i}}) - \sum_i(\mathrm{E}_{\mathrm{exp,i}} * \mathrm{f}_{\mathrm{exp,i}})$ where:

- $E_{del,i}$ is the delivered energy for energy carrier i;
- $E_{exp,i}$ is the exported energy for energy carrier i;
- $f_{del,i}$ is the primary energy factor for the delivered energy carrier i;
- $f_{exp,i}$ is the primary energy factor for the exported energy carrier i

Primary energy is the energy which has not undergone any conversion or transformation process. The primary energy factor allows converting the final energy in primary energy.

The importance of considering the energy balance in term of primary energy, instead of final energy, is due to the fact that it accurately reflects the CO_2 emissions being proportional to them (fig. 3). Reduction in primary energy consumption therefore reflects reduction of CO_2 emission. Proportions are distorted only when nuclear electricity is involved (Atanasiu 2011).

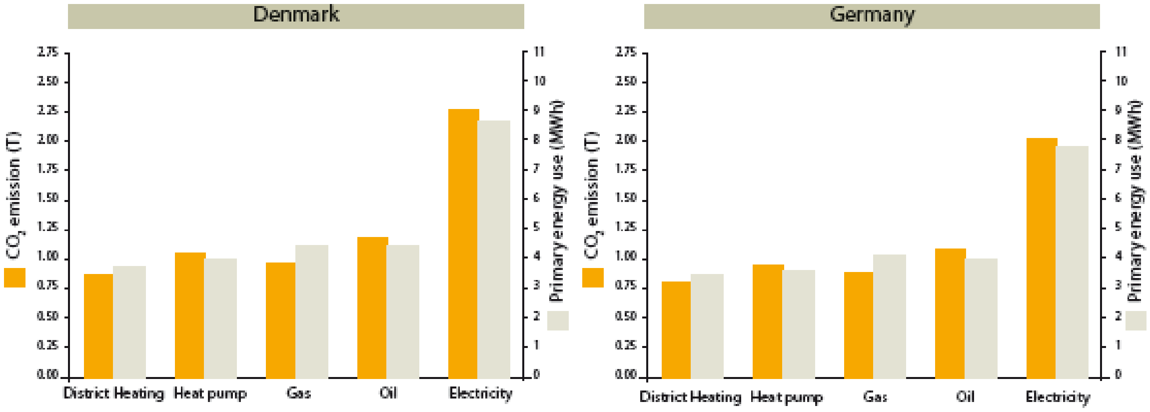


Figure 3: CO_2 emission and primary energy use for multi-family houses depending on the type of heating energy used (Atanasiu 2011)

2.3 BOUNDARIES OF NEARLY ZERO ENERGY BUILDINGS

Once given a technical definition of NZEB it is necessary to define the system boundary and clarify which flows are to be included or not in the calculations.

The EPBD recast states that energy performance of a building means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting (EU 2010, article 2). So according to the EPBD recast definition, electricity for household and outlets are not mandatory to be included. However the REHVA Task Force Report on a Technical Definition suggests the inclusion of electricity for household and outlets in the boundaries.

Another question is if on-site renewable energies have to be accounted as delivered energy. The choice of including or not on-site renewable energy in the delivered energy brings considerable consequences. Considering on-site production as part of the delivered energy would in fact enter in conflict with EPBD recast that states the positive influence of active solar and others renewables energies.

This positive effect in fact would not be taken into account in this case, since there would no difference in the balance between on-site energy and grid electricity. For this reason, from the interpretation of the EPBD recast, renewable energy produced on-site is not considered as part of the delivered energy. This guarantees that its positive influence of energy produced on site from renewables is taken into account. As consequence of these considerations the system boundaries considered for NZEB are the one shown in figure 4.

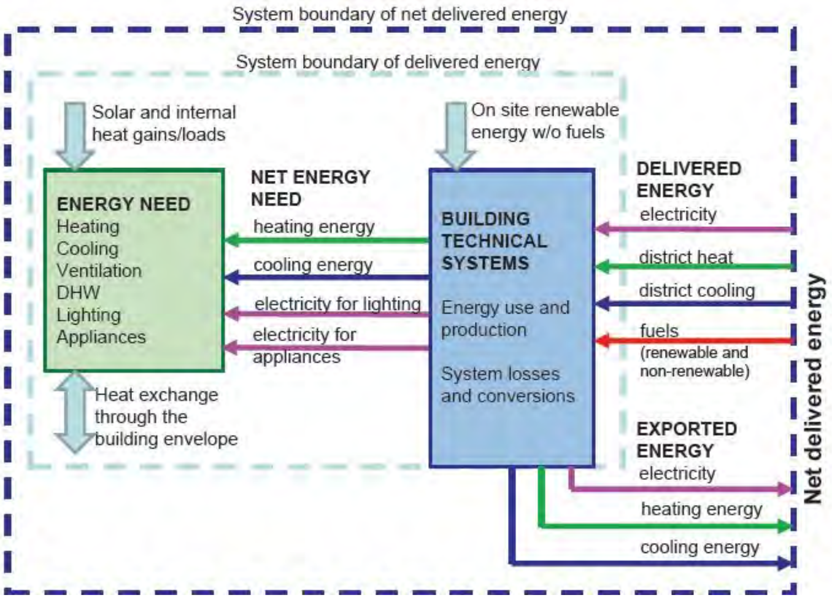


Figure 4: Energy boundaries of NZEB (Kurnitski et al 2011a)

2.4 CHALLENGES OF THE EPBD RECAST

Once set the definition and boundaries of NZEB there are controversial aspects that should be discussed concerning the prescriptions of the EPBD recast, as underlined by Atanasiu (2011).

The EPBD recast in fact raises some crucial challenges, but it does not specify their application, leaving open questions about the implementation of NZEB.

> Challenge 1: The directive advocates that "very significant extent of the energy demand, should be covered by renewable energy produced on-site or nearby", but it doesn't specify which should be the percentage covered by renewable.

Question 1: How to define the proper share of renewable energy?

> Challenge 2: The directive targets to comply with the EU commitments regarding GHG emission, but then the prescriptions focus on minimum requirement of energy performance.

Question 2: How to relate the nearly zero energy solution to the request of achieving nearly zero CO_2 emission?

> Challenge 3: The directive introduces a change of paradigm since the building start to contribute to the production of energy with on-site or nearby production.

Question 3: Should it be possible, within the definition of NZEB, looking at groups of buildings rather than at a single building?

Challenge 4: The directive states that minimum energy performance requirements for buildings have to be set “with a view to achieve cost optimal levels”.

Question 4: Are the NZEB targets cost-optimal with current market prices? Is the link between the principle of cost-optimality and the concept of NZEB necessary or optional?

Here follows an attempt of answering to these open questions.

Question 1: How to define the proper share of renewable energy?

Atanasiu (2011) proposes that a proper share of renewables could be set between 50%-90% to cover the remaining energy demand of the building. There are two main reasons that support the choice of a compulsory range of 50%-90%:

- the proposed range is in line with the NZEB definition from EPBD recast, which is asking that the energy demand of the building should be covered from renewable sources to a very significant extent, and
- the proposed range is likely to satisfy all the potential requirements for achieving the overarching targets for GHG emission.

Furthermore this share of renewables would also contribute to a paradigm change, moving from renewable energy being a minor substitute or complement of a fossil fuel based energy system towards an energy system where renewable energy is dominant while fossil systems exist only to a certain extent, for example to secure the supply during peak loads or as a backup source.

Question 2: How to relate the nearly zero energy solution to the request of achieving nearly zero CO_2 emission?

As shown before, primary energy indicator is a good parameter to link the energy consumption to CO_2 emission. Primary energy reflects both energy consumption and CO_2 emission of the building, and so the reduced energy consumption obtained with NZEB should lead to a proportional reduction of CO_2 emissions.

However Atanasiu (2011) suggests that to reflect the climate relevance of buildings’ operation, CO_2 emission should be added as supplementary information. This would lead to an easier and faster reading of the match between energy consumption and climate targets.

Question 3: Should be possible, within the definition of NZEB, looking at groups of buildings rather than at a single building?

Atanasiu (2011) underlines that nevertheless the EPBD recast clearly focuses on the energy performance of the individual building, there may be good reasons to address a group of buildings and to have a common energy balance for them.

Since one of the directive strategies is the use on-site production and since on-site central systems as an alternative to individual systems per building can yield benefits for example in terms of investment savings, better efficiency and better possibilities for seasonal storage, the possibility to assess the energy balance grouping buildings should be admitted.

> Question 4: Is the NZEB targets already cost optimal with current market prices? Is the link between the principle of cost-optimality and the concept of NZEB necessary or optional?

Atanasiu (2011) expects that there may still be a gap to be bridged between cost-optimal levels and NZEB levels by 2021. This worry is confirmed by Kurnitski et al. (2011b) that determined cost-optimal and NZEB energy performance levels following the REHVA definition (Kurnitski et al 2011a) and energy calculation methodology for NZEB national implementation (EC 2011b).

They conducted the model calculation for an Estonian detached reference house with heated net floor area of 171.1 m^2 .The results show that cost-optimal primary energy in the Estonian reference detached house was 110 or 140 kWh/(m^2a), including domestic appliances, and it was significantly lower than the usual common construction requirement of 180 kWh/(m^2a). This cost-optimal energy performance level led to 7 €/m^2 global cost reduction showing that a better building standard could bring saving to the global cost.

Nearly zero energy performance level, that was calculated as 40 kWh/(m^2a), however is not yet cost-optimal with current prices. The distance from cost-optimal to nearly zero energy performance level was about 239€/m^2 extra construction cost, about 20% more.

So how could be overtaken this obstacle? Atanasiu (2011) suggests that the link between the principles of cost-optimality should be optional and not mandatory. It should be given freedom to EU members for placing this threshold within a certain corridor with an upper limit, least ambitious, that corresponds to the cost-optimal level, and the lower, most ambitious, that would be set by the best available technology that is available and well introduced on the market, for example currently, triple glazing for windows.

In this way EU members may determine their national requirement for the buildings energy demand within the limits of the above corridor, according to the specific national context. Imposing a corridor and not a fixed threshold, will allow specific country solutions for achieving an overarching target (primary energy /CO_2-emissions), based on the most convenient and affordable balance between minimum requirements for energy demand and renewable energy share.

2.5 PREMISES FOR THE CHANGE OF SCALE

The advantages that clustering of building could yield in term of performance, and the fact that the nearly zero energy requirements are not yet cost-optimal with current price, underlined in the previous section, make wonder the pertinence of enlarge the concept of nearly zero energy to urban scale.

While in fact, the better performances of the urban scale can enhance the energy and GHG emission saving potentials, the enlargement to urban scale could trigger to economy of scale that would reduce the unitary cost of the investment.

The urban scale so could play a crucial role in challenging simultaneously the performance of nearly zero energy and the reaching of cost-optimality.

These are the premises that suggest the need of deepening the study on the main challenges and perspectives of widening from NZEB to Nearly Zero Energy Urban Areas. Therefore objective of the thesis is to discuss which would be the technical and economic implications and challenges of this change of scale.

3 FROM NZEB TO NEARLY ZERO ENERGY URBAN AREAS - STATE OF ART

In this chapter will be discussed the main challenges and perspectives of nearly zero energy applied to urban zones and how this enlargement of scale could enhance the achieving of the targets set for NZEB.

Firstly, following the current trends and also the EPBD recast, it will be focused the attention on the building factor, e.g. passive solutions as insulation and glazing, and energy system factor, as heating and electricity production, and their influence in the reduction of energy consumption and emission.

Secondly, going beyond the current trends, the approach will be widened including urban morphology as a parameter to control consumption and emission. As shown by studies about European Cities, like London, Toulouse and Berlin (Ratti et al. 2005) or Paris (Salat 2009) in fact, urban morphology can play a factor 2, being potentially able to reduce by 50% the consumption by itself (fig. 5). Such potentiality in reducing the consumption cannot be underrated.

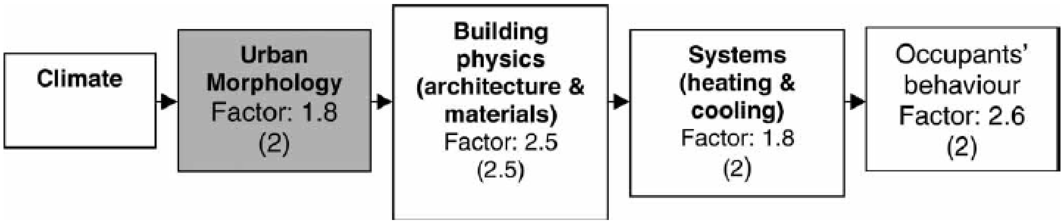


Figure 5: Factors affecting energy usage calculated by the Centre Scientifique et Technique du Batiment (CSTB) and by Massachusetts Institute of Technology (MIT) (Salat 2009)

Finally when considering urban areas, and including transport, the final energy consumption increases from 40% to 71% of the total European consumption (ADEME 2012). So including transport consumption in the boundaries of nearly zero energy would trigger significant reduction in GHG emission.

In this chapter therefore will be discussed how the concept of nearly zero energy could benefit from the enlargement of scale both in the reduction of emission and costs, starting from the common approach concerning building and system factors and secondly widening the approach, studying the implications of including urban morphology and transport as controlling parameters.

3.1 POTENTIALITIES OF BUILDING AND SYSTEM FACTOR

3.1.1 FOSTERING ALTERNATIVE STRATEGIES

NZEB start a new paradigm, being the building not belonging anymore on the demand side, but contributing simultaneously to the supply of energy.

From this perspective including the clustering of buildings and mixing of different building types greatly affects the opportunities for and cost of district heating and cooling systems (IPCC 2007) and thus the efficiency and applicability of a range of energy supply systems.

It is only by combining a number of consumers to one bulk buyer that technologies, widely promoted by EU, as district heating, cogeneration (CHP), tri-generation, biomass, and solar energy, can provide alternative strategies, as pointed out by Nast (2004).

On supply side the assessment of the single building therefore will fail to consider certain measures or technologies, which are not applicable, either for technical or for economic reasons, to small consumers (Koch 2009).

Central supply in fact can yield benefits for example in terms of investment savings, better efficiency and better possibilities for seasonal storage (Atanasiu 2011). In addition, with any centralized systems maintenance cost is concentrated in one location and consequently is reduced in comparison with a single building (UEI 2002).

When considering centralized systems, different distributional solutions can be approached with different strategies to take advantages of their peculiarities.

For example when we are in presence of integration of office, laboratory, biotech, retail, and residential spaces with contrary schedules of heating and cooling, distributed heat pump could be a solution to take advantage of diverse load requirements of the development reducing energy costs (fig. 6).

A condenser water loop is proposed to cycle water between the areas that produce an excess of heat and those areas that have a demand for heat. Since the pipes are laid into the ground, the ground becomes a coupled storage mechanism for the system. During the peak heat production hours of the daytime when all of the offices and laboratories will be dumping excess heat into the system, the soil will help to store that energy for later release to residential or early morning demands. The greatest efficiency of this strategy would be realized when heat-producing sites are located adjacent to heat-demand sites (UEI 2002).

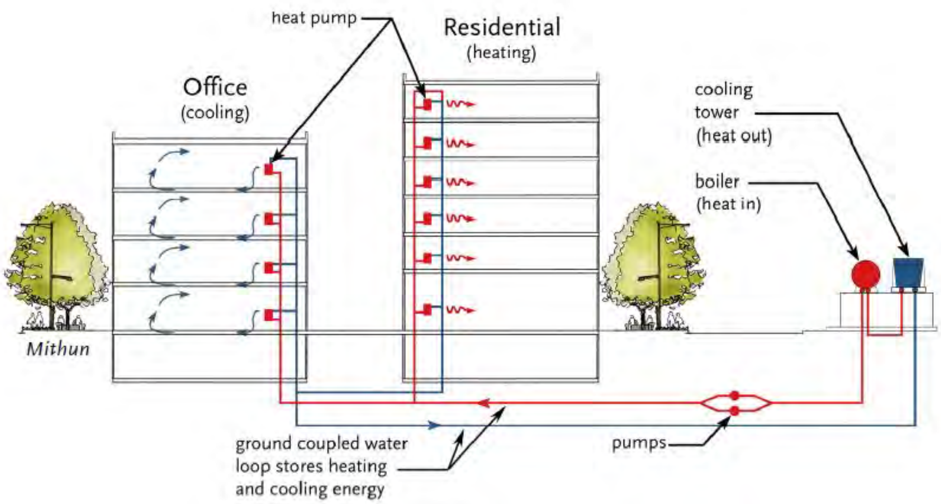


Figure 6: Distributed heat pump (UEI 2002)

Since buildings need both electricity and heating, CHP can be an alternative strategy since it gives the advantage of generating simultaneously thermal and electrical energy in a single process (fig. 7). In electricity generation, waste heat production is an invariable side effect. It follows then that energy efficiency as a whole is optimized when the waste heat is reclaimed for building use rather than exhausted to the environment.

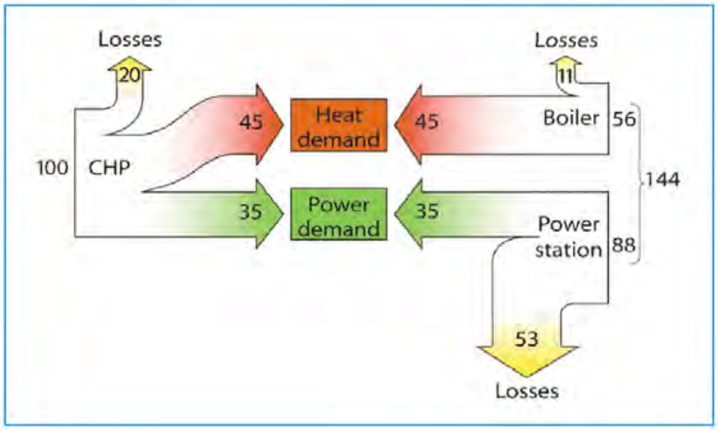


Figure 7: Comparison of CHP efficiency with a conventional solution (CIBSE 2004)

Through the utilization of heat exchangers and heat transfer technology this heat can be used for district heating, and therefore the cost of heat generation can be greatly reduced (UEI 2002). In this way, optimum use can be made of the energy available from the fuel and CHP can convert 90% of the energy of the fuel into electrical power and useful heat compared with conventional power generation which has a delivered energy efficiency of around 30-45% (CIBSE 2004).

CHP in addition can contribute to the reduction of the emission not only through higher efficiencies, but also through the use of renewable fuels. Though the most common used fuel for cogeneration is natural gas, the engine of the CHP can run with biomass, thus being GHG neutral, since the emission are compensated by the CO_2 consumed by the plants used for the production of the biomass during their life.

The location of the connection is not critical, as the electrical power will flow to the loads regardless of location. However for the purposes of heat recovery, the plant should be close to the concentration of buildings which can use the heat. If a suitable heat demand is not available, a secondary option is to utilize the waste heat in an absorption process to produce chilled water for cooling.

Cogeneration is individuated by EU Directive 2004/8/EC as an important measure to save energy in the Community with regard to saving primary energy, avoiding network losses and reducing emissions, in particular of GHG. In addition, efficient use of energy by cogeneration can also contribute positively to the security of energy supply and to the competitive situation of the European Union and its Member States, reducing the dependence from importation (EU 2004).

However although CHP can be small enough to supply single buildings, for example through micro-turbine, with power lower than 5kWe, it's only with huge CHP that better efficiency can be achieved with lower costs and CO_2 emission released since the cost of even a small district heating network is so high that it cannot be offset by improvements in efficiency or lower costs of larger CHP systems (Woods et al. 2005). Besides biomass systems can be cost effective only with the increasing dimension of the system (Nast 2004).

Therefore diffusion of CHP, advocated by EU, seems to show better economic and technical potentialities only with the increasing of the dimension, and so when it's integrated in an urban scale and not at building level.

Moreover solar thermal offers interesting strategy to reduce dependence from the grid only when is available a huge heat storage. Since there is a significant gap of solar irradiation between summer and winter, and periods of peak solar radiation and peak heat demand do not coincide, as a result the solar fraction cannot be 100% without seasonal energy storage (Roth 2013).

Building solar thermal systems in fact are generally designed to cover a solar fraction not higher than 55-60% to prevent the risk of stagnation due to overheating of the system in summer (Kingspan 2013).

Higher solar fractions therefore could be reached only through seasonal thermal storages that would allow trading in winter the heat accumulated in summer. The dimension of the storage however is a prerogative for the applicability of this strategy because in small storages the heat losses would be too high and would not allow seasonal trades (Nast2004). 100% coverage of heating needs through solar thermal can be feasible therefore only at urban scale.

Finally at urban scale the intervention could tackle also public lighting consumption, which is estimated to account for about 2% to 3% of total public sector energy consumption (SEAI 2012).

When considering the potentiality of assessing the energy balance at urban level instead of at building level, the availability of new technical solutions is not the only variable to consider. The aggregation of buildings in fact seems to greatly influence the consumption pattern.

3.1.2 ALTERATION OF CONSUMPTION PATTERN

The consumption pattern is another indispensable variable in the design of the supply system. It determines the optimal power generation capacity and thus influences the cost of the system. It is in fact depending on the peak load that the power supply systems are dimensioned, and the total consumption is consequence of the consumption pattern.

As explained by Willis & Scott (2000) (fig. 8), individual consumptions are unpredictable, and their fluctuations along the day is unrevealed. The behavior of the single household seems fortuitous. This appearance is caused by the inconsistent individual use of household appliances for short periods (Paareto 2009). However when more households are aggregated, clear consumption pattern seems to emerge and the total consumption is smoothen thus reducing the power needed of the supply system.

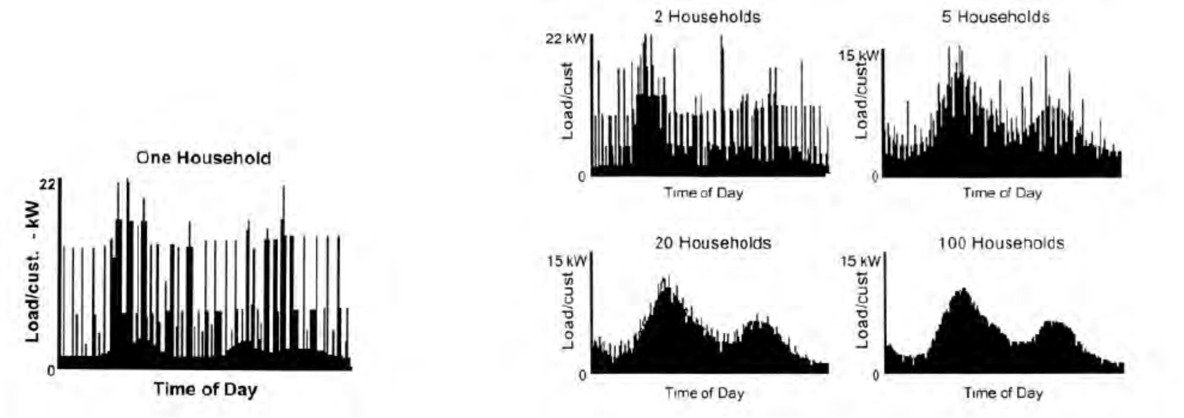


Figure 8: Consumption pattern with the increasing number of households (Willis & Scott 2000)

Further advantage consists in the temporal resolution. Reducing the discrepancy between highest and lowest load, the necessity to store the energy, to compensate the fluctuation, is reduced. This influences relatively the electricity generation, since feed-in tariffs allow electricity energy export, but it strongly affects thermal production, which needs a tighter temporal match between conversion and use to avoid the need for large storage capacities (Koch & Girard 2011).

The discussion about spatial scale and time resolution takes place in various contexts. An obvious example concerns the implementation of a district heating network in a given neighborhood.

Considered in space and time resolution, the number and the type of selected buildings to be connected to the network have great technical, financial and environmental impacts due to the sizing of infrastructure, as well as base and peak-load technologies. This leads to the conclusion that on the enlarged scale of a neighborhood are expected to deliver much better results than on the scale of individual buildings *(*Koch and Girard 2011*)*.

3.1.3 **TRIGGERING ECONOMY OF SCALE**

The consideration above suggests that the enlargement of scale, in addition of improving the performance of nearly zero energy, can be a support to reduce the cost of implementation, and thus ease the reaching of cost-optimality, which is a target of the EPBD for NZEB but as already underlined is not yet cost optimal with current prices.

Beyond the reduction of investment due to the smaller power of the supply system, energy storage and the reduced annual bill due to the reduced consumption, a better chance to reach cost optimality at urban scale is suggested by the fact that the increased scale is linked to a bulk purchase of building materials, which would inevitably reduce the purchase price.

A European market research conducted in 2012 by EPIA (2012) (table 1) shows how the unity price of photovoltaic panels, that is between 1700 and 2300 €/kWp for a system between 3 and 10 kWp would reduce to 1250-1800 €/kWp for a purchase of 500kWp with a reduction between 22% and 26%, that could reach 26-29% for a system of 2,5MWp

Table 1: Photovoltaic economy of scale with increasing system size (EPIA 2012)

Photovoltaic EU market price				
Power installed (kWp)	0-3	100	500	2500
Price (€/kWp)	1700-2300	1400-1900	1250-1800	1200-1700
Economy of scale (price reduction)		17%-18%	22%-26%	26%-29%

An analogous study conducted by BINE (Schnauss 2008) (table 2) has shown significant economy of scale also for solar thermal with reductions from 650-700 €/m^2 for a system of 10-20m^2 to 350-480 €/m^2 for surfaces of 50m^2 with a reduction of 24%-31%. The reduction can reach also 46% of the price when the surface installed is higher than 50m^2.

Table 2: Solar thermal economy of scale with increasing system size (Schnauss 2008)

Solar thermal German market price				
Surface (m^2)	10-20	20-30	30-50	>50
Price (€/m^2)	650-700	530-580	450-530	350-480
Economy of scale (price reduction)		17%-18%	24%-31%	31%-46%

Analogous economies of scale are supposed to be verified for passive solutions as external thermal insulation system (ETICS) and glazing. These have been assessed resorting to a generator of price (CYPE 2013), available in Portugal, which takes into account the concrete characteristics of the specific project, thus underlining the variation in prices with the increasing of the dimension of the investment. The simulation has been run comparing a semi-detached house, with a floor area of 300 m^2, with a neighborhood with a floor area of 30.000m^2, for around 500 inhabitants, composed by 100 similar houses in row (fig. 9).

The results showed how for the semi-detached house a 5 cm ETICS would cost 66,8 €/m^2 while a PVC framed window system would cost 237€. With the considered size of neighborhood instead, they would cost respectively 50,6€/m^2 and 181€ with a reduction of 23-24%.

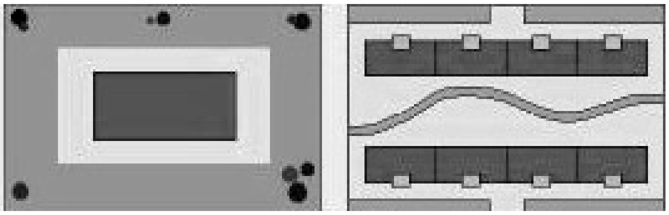


Figure 9: Scheme of the semi-detached house and the neighborhood with row houses considered for the simulation with the generator of price (CYPE 2013)

What interests about this analysis is not the price in itself, which varies depending from the peculiarity of the national market and is influenced by annual variations, but the economy of scale that it highlights, which is anything but negligible, and that could help to achieve cost optimality.

The enlargement of the scale from building to urban area, even when considering only building and system factor, has therefore a great technical, financial and environmental impact due to the reduced consumption, power of the system, size of the storage and thanks to the reduced unity costs of the investment.

3.2 THE FACTOR 2 OF URBAN MORPHOLOGY

The potentiality of the assessment of the urban scale does not deplete to building and system level. Urban morphology is a parameter responsible for creating or at least modifying energy demand, in the first place for transport energy. But urban morphology also has a significant influence on heating and cooling energy consumption, through inter alias urban heat island effect, shading between buildings, and the possibility to take advantage of passive sources as natural light, ventilation and solar gains (Bourdic & Salat 2012).

The Centre Scientifique et Technique du Batiment (CSTB) Urban Morphology Laboratory (Salat 2009) studied the impact of urban morphology on building consumption in Paris. Calculating the metrics of all of Paris city fabric and modeling 96.000 Parisian residential buildings, they compared three urban morphologies and their energy consumption.

The calculations were undertaken keeping identical all the factors not dependent on the urban form, building envelope, systems, and people behavior, underlining in this way only the impact due to urban form. The result shows that the modernist texture consumes 1.8 times more energy for heating than contemporary or traditional Paris urban blocks (fig. 10).

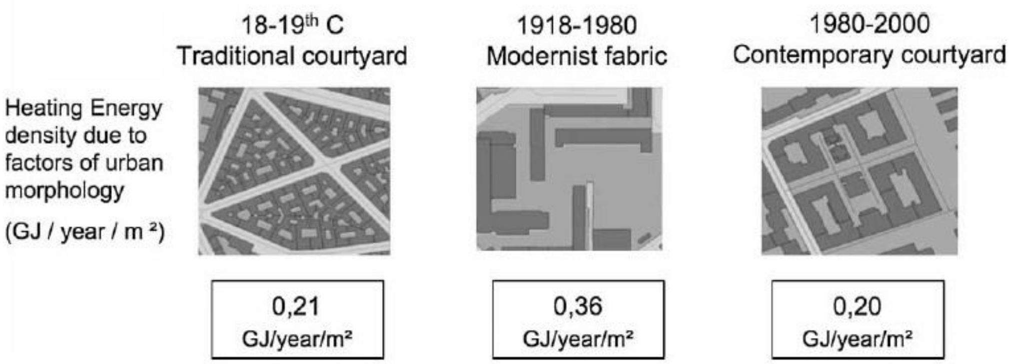


Figure 10: Effect of urban morphology on the energy need of building stock in Paris (Salat 2009)

The study on Paris urban block confirmed a previous study conducted by the University of Cambridge and Massachusetts Institute of Technology (Ratti et al. 2005) that suggest that urban morphology can play a factor 2 in reducing building energy consumption. This means that urban morphology has the potential to halve a city’s energy consumption and carbon emissions reducing it by 50%.

But which are the reasons of this gap of consumption due to urban form? How urban morphology influences the consumption and how the parameters of urban morphology can be controlled to reduce consumptions?

3.2.1 **BUILDING SHAPE PARAMETERS**

The shape of buildings is an aspect strictly related to energy consumption. Two core parameters are the (1) surface-to-volume ratio or compacity (March 1972) and the (2) ratio of passive-to-non-passive zones (Ratti et al. 2005). These parameters, despite could appear to be linked to the design of the single building, since they depend on its shape, are considered as urban morphology variables, being strongly bound to the constriction introduced by urban planning decisions.

$$(1)\quad Compacity = \sum \frac{S}{V^{2/3}} \qquad (2)\quad Passive\ Ratio = \frac{\sum PassiveVolumes}{\sum BuiltVolumes}$$

The compacity is relevant to energy consumption of building since it represents the amount of surfaces exposed to the outside environment (S), which is responsible for heat losses.

Passive ratio instead measures the potentiality of the building to use passive resources as daylight, sunlight and natural ventilation. All the perimeter zones of a building lying within 6 meters of the facade, or twice the ceiling height, are classified as passive while all other zones are considered non-passive (Salat 2009).

These two parameters have to be considered carefully. Minimizing the compacity in fact would minimize heat losses but would simultaneously reduce the possibility to exploit sunlight, while maximize the passive ratio would have the opposite implication.

Ratti et al. (2005) suggest that passive to non-passive ratio is a better indicator of energy consumption since they found that it has a greater influence to final consumption. Through a simulation, with a digital elevation model, a comparison between three case study - cities of London, Toulouse and Berlin - and keeping equal all the parameters not linked to morphology they showed how heat losses through the building envelope are not the most prominent component of the total energy budget, and how the possibility to benefit of passive sources as daylight and natural ventilation have a greater influence. The results underlined how passive volumes present a significant reduction in energy consumption, almost 50%, compared to non-passive volumes.

It's important to notice that the benefit from passive gain is only potential. Passive gains could bring to negative effect if the passive solution is not correctly designed or used. If for example the possibility of naturally ventilate the apartment is obstructed, in summer its benefit can be exceed by the overheating of the exposed surfaces turning the passive surface counter-productive.

The greatest benefit given by passive ratio compared to compacity is not an absolute truth. The result is influenced by the peculiarity of the cities chosen, so in countries with more extreme winter conditions than United Kingdom the heat losses can dominate and the role of compacity can predominate, while southern location could further benefit from passive gains.

The influence of these parameters has to be assessed case by case, but it's important to be aware of their significant influence that they can play in the control of consumption.

3.2.2 POPULATION DENSITY

Population density is another parameter which greatly influences consumption and cost of the infrastructures. Lower densities with higher proportion of detached and semidetached houses determine an increasing of energy use as verified by Duun et al. (1988) comparing different housing type with the same floor surface of 120m^2 in Oslo (fig. 11).

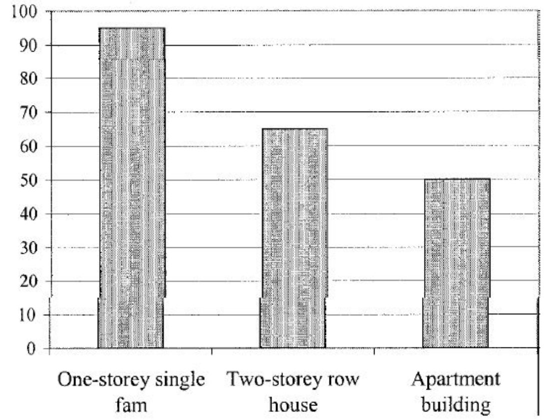


Figure 11: Variation in energy requirement for space heating (kWh/m^2) between different housing types with 120 m^2 of residential floor area. The figure applies to Oslo climate conditions (Duun et al. 1988)

This relation between typology and consumption is confirmed by a more recent study conducted by the US Environmental Protection Agency (EPA 2011) for the American building stock (fig. 12).

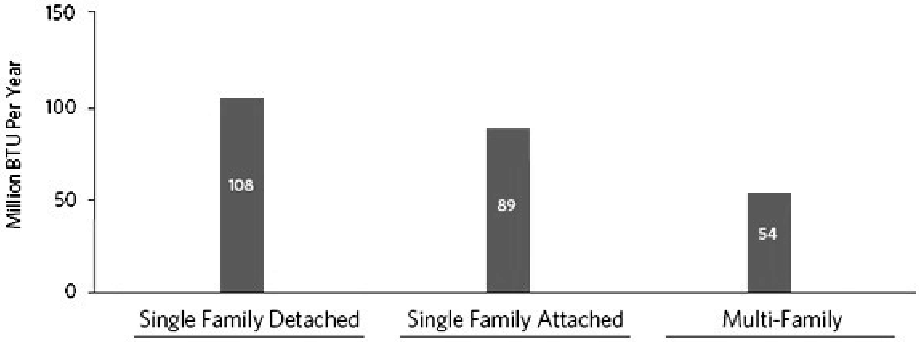


Figure 12: Energy requirements in different housing type in USA (EPA 2011)

Density furthermore influences the applicability of alternative strategies as district heating and the cost of the infrastructure. Higher density of urban area results in a relatively higher heat demand density and therefore is essential to allow the applicability of the alternative strategies that the urban scale make available.

A significant heat demand in fact is a prerogative for the viability of a CHP since the great efficiency of cogeneration is due to the utilization of the waste heat released in the electricity production process. CHP is in fact usually oriented to meet the heat demand and not a specific power outputs, and so is dependent on a high density of heat demand (Koch 2009).

The density is furthermore important since the heat consumption should be located in proximity of CHP to reduce heat losses in the distribution (UEI 2002). There is therefore a negative correlation between density and cost for this type of infrastructure including the operation (Koch 2009).

It seems clear therefore that, concerning consumptions, higher densities seem to be more suitable to achieve nearly zero energy thanks to lower consumption and to allow the implementation of alternative strategies as district heating.

3.2.3 **URBAN HEAT ISLAN EFFECT**

Another aspect influencing heating and cooling consumption in buildings is the urban heat island effect (UHI). UHI refers to the generally warmer urban temperatures compared to those over surrounding non-urban areas. The UHI is typically presented as a temperature difference between the air in the urban area and that measured in a rural area outside the settlement ($\Delta T_{u\text{-}r}$).

Oke (1981) found a relationship linking street geometry and climate effect. It shows how the maximum variation of air temperature between the urban and the surrounding rural areas ($\Delta T_{u\text{-}r\ (max)}$) increases with the raising of the ratio between height of the building (H) and width of the street (W), or alternatively with the reduction of the sky view factor ψ_{sky} (fig. 13). It is therefore urban morphology function since higher buildings with narrow streets would contribute to increase UHI effect.

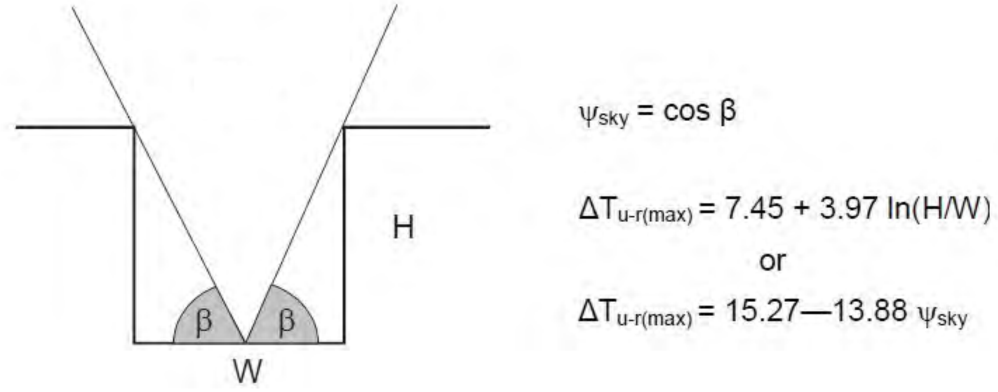


Figure 13: Correlation between heat island effect and shape of the street canyon (Mills 2013, Oke 1981)

Whether the UHI is desirable or not it will depend on the background climate. In cold Countries the UHI would reduce the heating needs while in warmer countries may produce stressful condition.

In case of negative effect of UHI, in places where it produces stressful condition, the proximity of green parks can soften UHI, reducing the difference of temperature between rural and urban (fig. 14). The introduction of green areas in the urban environment seems therefore a possible strategy to mitigate the negative effect of the UHI.

Figure 14: Positive effect of green areas on the UHI (ΔTu-r) (Mills 2013)

The purpose of this section is not to propose universal solutions, since an answer would not suit to all the cases, but is to understand the importance of minimal thresholds that have to be taken into consideration since they strongly influence the energy consumption.

In the EU fight to reduce GHG emission the potential of a factor 2 cannot be overlooked, it is therefore important to understand which are the parameters that need to be corrected and how they influence consumption. The potential saving related to urban morphology is particularly interesting because it’s potentially for free. Making the right choice at the planning stage should not involve a priori an increase of price.

This factor 2 however can be triggered only if it is controlled at urban before than at individual building scale, since urban planning defines the rules for building design. Wrong choices taken during the urban planning process affect the choices when designing the building. Without enlarging nearly zero energy to urban area this potential could be missed.

Summing up all these considerations it seems more clear which are the challenges of NZEUA:

- 50% saving in consumption due to proper choices taken at urban design stage, choosing a better urban form.
- Homogenization of consumptions thanks to the aggregation of group of consumers.
- Possibility of implementing more efficient alternative strategies as district heating and cogeneration, contributing to a more rational use of energy thus reducing emission and dependence from the grid.
- Economy of scale that would reduce significantly the initial investment and so the time payback.

Considering all these advantages therefore the energy balance of the urban neighborhood therefore seems a necessary prerequisite to grasp the full technical and economic potential of NZEB.

3.3 INCLUDING TRANSPORT IN NEARLY ZERO ENERGY

Since European final energy consumption increases from 40%, for buildings, to 71% when considering the urban scale, with a 31% of the consumption due to transport (ADEME 2012), when discussing the convenience of applying nearly zero energy to urban scale seems inescapable wondering if also transport should be included in the boundaries of nearly zero energy.

As underlined by Bourdic & Salat (2012) urban morphology seems to have a great influence in transport energy demand. But how this link reveals itself, and how transport behavior can be controlled?

According to theories of transport, travels are influenced by the reason that makes people move and the discomfort involved when travelling to this destination, so the proximity between different activities facilitate non-motorized means. This is due to the fact that the discomfort involved by the time needed for walking is reduced, thanks to the short distance and the discomfort involved. The time needed to look for a parking could become predominant, making the use of the car less attractive (Nunes da Silva 2011). Shorter distances between facilities so would ease the use of not motorized means thus contributing to lower energy use and emissions (Naess 2001).

This correlation between access to facilities and use of car is confirmed by a study conducted by Naess & Jensen (2004) in Frederikshavn, a small village in Denmark that as many European cities have had a concentration of workplaces and service functions in the central areas.

The result of the survey conducted in this village shows how the distance from the downtown, which correspond to the access to facilities, influences the resident travels (fig. 15). The correlation between the distance from their houses and the facilities is not linear. From the graphic can be noticed how from 1 to 1,5 km from the downtown there is a low variation of distances travelled and how above this 1,5km the travelled distance rises quickly till 5 km. For higher distance than 5 km the travel distance does not determine further increases in the distance travelled.

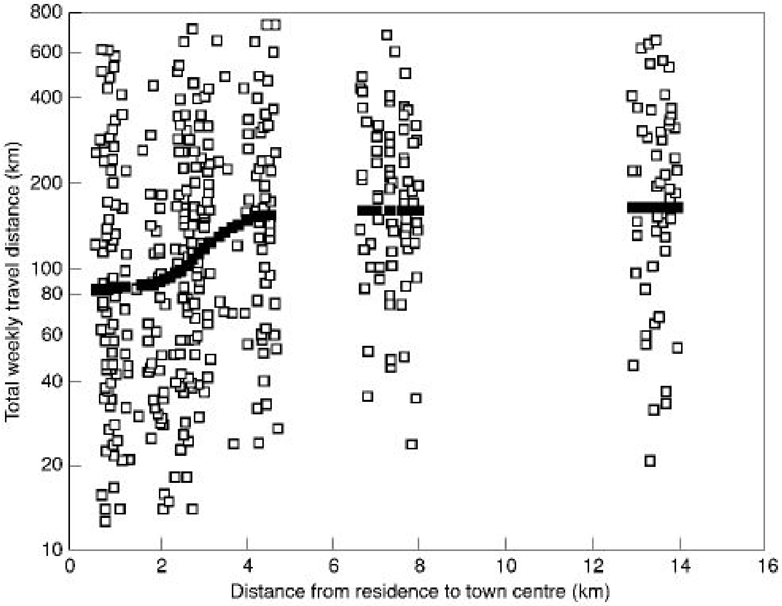


Figure 15: Total travel distance among respondents, living at different distances from the center of Frederikshavn (Naess & Jensen 2004)

The results also show how the distance from the facilities does not influence only the travelled distance but also the modal choice. Figure 16 illustrates how non-motorized modes account for a higher proportion of travel distance for residents living near downtown compared to people living in surrounding areas (Naess & Jensen 2004).

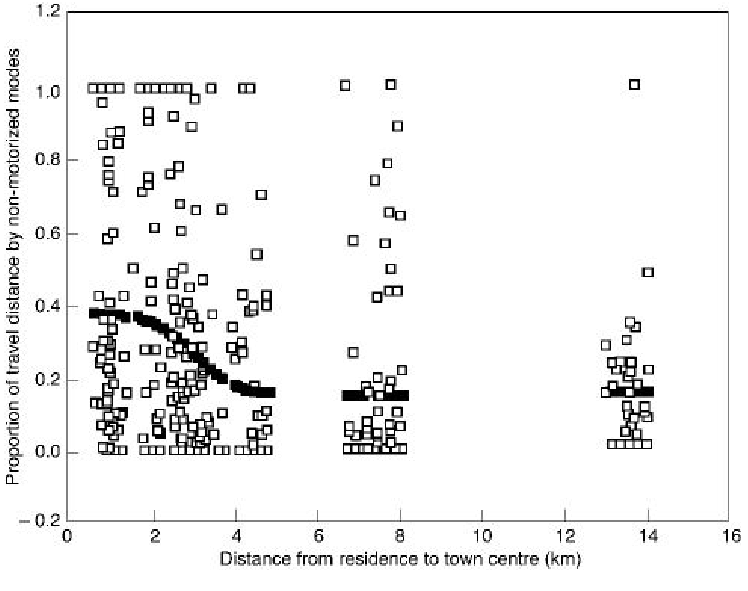


Figure 16: Proportion of total distance travelled by non-motorized modes among respondents living different distances from the center of Frederikshavn (Naess & Jensen 2004)

The results of this research suggests that a radius of 1-1,5 km from the facilities is a good distance to reduce the distance travelled by car and favor non-motorized mobility. For this reason mixed-use pattern in opposition to mono functional neighborhoods, reducing the distance from residences to local facilities and services as groceries, stores, primary schools, kindergarten and workplaces seems a proper model of sustainable urbanization.

The assumption that mixed pattern favors a lower use of cars is supported by a survey conducted by Masnavi (2000) that studies the correlation between low and high density and single or mixed use patterns and modes of transportation in four neighborhoods in Scotland. Garnethill and Hyndland are two high density neighborhoods in Glasgow, respectively with mixed use and single use pattern, while East Mains and Stewartfield are two low density neighborhoods in East Kilbride New Town, with respectively mixed use and single use pattern. The results of the survey (fig. 17) shows how higher densities are associated to lower share of use of private car, and how mixed use pattern are more suitable for walking since they have an easier access to the destination point.

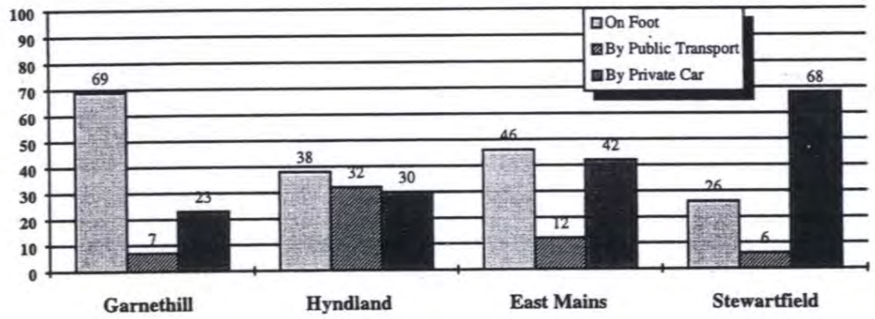


Figure 17: Accessibility of facilities by different modes of transport (% average of all trips) (Masnavi 2000)

The study underlines how different structures do not influence only the behavior but also the inhabitants' perception of being able to manage without car. While 51% of the inhabitants of the mixed use high density development feel to be able to manage without cars to access the facilities, for the other urban structures between 61% and 79% of the respondents feel unable to access them without car.

The results suggest that high density and mixed use guarantees the best behavior in term of accessibility and dependence from motorized means and that can reduce use of private car by 70% reducing the distance travelled for non-work trips by 75% compared with low density single use urban form.

The study underlines also the importance of higher density, which testifies a better behavior than low density. This circumstance is a consequence of the fact that higher densities imply the opportunity to allocate local facilities and local shops and workplaces in the area, since the catchment guarantees a sufficient number of users to make it economically viable (EU 2004).

Higher densities furthermore can support the realization of an efficient public transport system that can contribute to an additional reduction of the use of the car to reach those facilities that cannot be found at a walking distance. High density is therefore an indispensable prerequisite to develop a good public transport system, since low densities cannot target a sufficient number of people to make it function economically (Frey 1999).

The correlation between travel behavior of the residents and density and accessibility to facilities has been verified in other studies conducted in Paris (Mogridge 1985; Fouchier 1998), London (Mogridge 1985), New York and Melbourne (Newman & Kenworthy 1989), San Francisco (Schipper et al. 1994), Greater Copenhagen (Hartoft-Nielsen 2001), Greater Oslo (Næss et al. 1995), Bergen (Duun 1994), and Trondheim (Synnes, 1990).

The analysis proposed shows how people's transport behavior is strongly influenced by the structure of the urban area, and that intervening on parameters as density and distribution of facilities transport consumption can be reduced. This reveals how morphology deeply influences transport even when municipal urban policies are not controlled.

Further reduction of private motorized means could be achieved optimizing a proper structure of the urban area with urban policies that could work in synergy, reducing further the need of car movements. Remarkable results could be achieved through traffic calming measures, parking policies, more efficient public transport and initiatives as car-sharing to reduce the need of owning a car.

Proof of this potentiality are the outstanding results achieved in eco-neighborhood as Vauban, in Freiburg, where the 70 % of the trips are done using public transport, walking and cycling (Broaddus 2010) and BedZED, in Sutton, that shows a reduction of 65% on distance travelled by car compared to national average, with car ownership reduced by 39% (Lazarus 2003). A more detail discussion of these two reference neighborhoods will be given in the next section.

The dependence of travel modal choice from density, mixed use and proximity and urban policies shows how urban planning and design can have a substantial impact on private car usage thus reducing consumption and CO_2 emission.

Therefore this work suggests that if the concept of nearly zero energy will be enlarged to urban zones the opportunity to include transport emission in its boundaries should not be missed. The possibility of influencing an aspect responsible for the 31% of final EU consumption cannot be overlooked in the EU battle to reduce GHG emission.

3.4 SUSTAINABLE NEIGHBORHOOD REFERENCE CASES – ENERGY

Once examined the challenges of nearly zero energy at urban scale, the purpose of this section is to analyze the state of art of neighborhoods that target to a significant reduction of energy consumption and whose energy management is organized at the neighborhood scale despite of building level, to understand how the urban design principles and low energy solutions have been applied in some of the best practice examples.

Even though in fact the concept of nearly zero energy is not already extensively discussed at urban scale, there are examples of neighborhoods that are planned with an integrated approach with the purpose of guarantying a sustainable development, including as a key aspect a more rational use of energy.

As reference examples have been chosen two neighborhoods that are pooled by a common goal, the sustainable development, but that start from different premises. These two cases are also interesting to show how this approach can be conducted at very different scales.

In fact while Bed Zed is a small development on an area of 1,7ha, Vauban is a development of 38ha. This difference is really interesting to see how the implementation of sustainable neighborhoods is not bound to a specific constrains, but different approaches can be applied depending on the size of the settlement.

BedZED, a neighborhood in south of London, is a private investment that, targeting sustainability, does not ignore the return on investment. So focusing to low carbon solutions it gives attention to the balance between increased costs of the investment and added value. This example shows how sustainability can be financially advantageous also for private investors.

Vauban, a municipal investment in Freiburg, shows how public interest coordinated with participation between the different stakeholders, and involving the residents, can enhance synergies that contribute to improve the quality of the development.

Both the developments have been planned taking care of all the aspects of the integrated approach as integration with the site, resources, including energy water and materials, transports and socio-economic dynamics. However in this analysis will be discussed only the aspects mainly related to nearly zero energy:

- urban design approach,
- energy management,
- transport policy.

3.4.1 **BEDZED**

The discussion about BedZed is mainly based on the “BedZED: Toolkit Part II. A practical guide to producing affordable carbon neutral developments” (Lazarus 2003), a document released by BioRegional to promote practical solutions in reducing the environmental impacts of new developments.

BedZED (Beddington Zero Fossil Energy Development) is a private initiative of Architect Bill Dunster to produce a carbon neutral development. It is a small mixed used neighborhood of 1,7ha realized between 2000 and 2002 in Sutton, in south of London. It combines 82 dwellings with 271 habitable rooms and 2500m^2 of works and commercial spaces.

Figure 18: Picture of the square in BedZED (Lazzarus 2003)

It challenges conventional approach of planning, confronting with sustainability in all the aspects of the project. Every aspect of construction has been assessed in term of its environmental impact. For example materials have been selected for their low environmental impact, sourcing them locally and recycled when possible. This approach at construction stage determined a reduction of 20-30% of the embodied environmental impact

Since BedZED is a private investment, particular attention is given to the financial upturn of the implemented strategy. In addition of the environmental impact, the costs and added value of the different alternatives have been assessed.

3.4.1.1 **Urban design**

BedZED design takes the emphasis away from the car, keeping the heart of the neighborhood car free, limiting the speed in the residential part to 30km/h and placing the parking spaces around the edge of the site. In this way people enjoy the almost car free environment that encourage social life and guarantee the safety of the children playing.

The aim is to create a pedestrian and cyclist friendly environment that favors the livability of the neighborhood and decreases car travels thus reducing carbon emission. To promote walking and cycling, on sites facilities as social spaces, bars, sport and childcare facilities and local shops are located in the neighborhood. BedZED also provides ample cycle storages, and guided rides and cycling events are organized to educate people and change their attitude.

To maintain high standards of affordable mobility in addition to two bus routes, which are available to reach the centers of the nearest town, BedZED offers a car-sharing service to the residents, in order to guarantee the accessibility also to downtown facilities and the travels needs without the need of owning a car.

Car ownership is in fact one reason of the high use of car. People buy car to have mobility independence, and then they use it for most journeys because, having paid for the fixed cost of the car, they have financial advantages to use it for as many travels as possible (Lazzarus 2003).

Not owning a car has further advantage not having to pay £200 for annual parking permit. People who want a car are encouraged to change to electric vehicles since parking is free for them, and electric cars receive free fuel since it is provided for free in charging point supplied by 777m^2 of photovoltaic panels that produces power enough for 40 electric cars.

3.4.1.2 **Planning gain**

To guarantee the payback of the investment the designer were able to increase densities without compromising design quality and environmental performances thanks to the introduction of the Green Transport Plan and to the colonization of the roof by green gardens.

The Green Transport Plan, limiting the use of the car in the neighborhoods and giving priority to pedestrian and cyclist, allows a reduction of both parking places and surface taken by roads. Green terraces in the meanwhile make attractive the high occupation density, providing private garden at densities that normally would allow only a balcony.

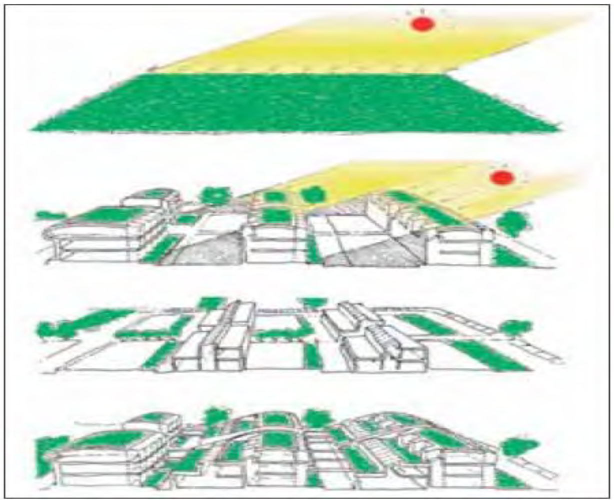


Figure 19: Design strategy of the green terraces (Lazarus 2003)

The reduction of the space occupied by streets, and the allocation of green spaces on the roofs and terraces allowed the developers to contract with the municipality an increasing of the built volume from the restrictions of the municipal plan, since with these solutions it has been satisfied the regulation request of public spaces.

Combining these solutions in fact the municipality allowed the developers to increase the construction value of the development by achieving 271 habitable rooms plus 2.500m^2 of works unit and commercial space although planning permission was limited to only 250 habitable rooms and no commercial spaces**.** This allowed to reach a population density of 148 inhabitants/ha and employment density of 119 workers/ha.

BedHED – 27 terraced houses and 60 flats.
250 habitable rooms.

BedZED – 82 units, 1,2 3 & 4 beds.
271 habitable rooms.

Figure 20: Comparison of a possible scheme allowed with the initial density permission with the realized design reached thanks to the planning gain (Lazarus 2003)

The additional 3.009m^2 of built area, with related added cost of £2,5millions, enables the developer to generate an extra value of £3,7millions, with resulting added revenue of £1,2millions.

3.4.1.3 **Energy**

Energy plays a key role in achieving zero fossil energy development. First objective in BedZED is the reduction of thermal demand of the buildings, and later the production of the low amount of energy, heat and electricity needed through efficient and renewable supply systems.

To reduce to minimum consumptions buildings have a really tick insulation, 30cm, that encircle the entire profile and eliminate the cold bridges. The southern elevation have a wide glass surface, to take advantage of the heat gains, with two skins of double glazing, while in all the other orientations the windows are triple glazed and are kept to minimum surface possible to reduce the heat losses. Dense concrete block works provide the needed thermal mass to accumulate heat during hot hours, and release it in colder hours keeping the internal condition comfortable.

The combination of all these solutions reduces the heat losses to such an extent that eliminates the need of central heating systems. Occasional gains as cooking, use of electric appliances and people’s heat provide the necessary heat to keep comfort condition inside the dwellings.

The heat gains that occur on the south façade and in the kitchen are needed to be spread all over the apartment. With this purpose internal partitions are not insulated and internal doors undercut. The internal ventilation is guaranteed by passive ventilation system with wind cowls on the roof, with heat recovery at 70 %.

The average space heating needed with this passive design is 16,2kWh/(m^{2}a) that is the 12% of the space heating demand of UK average home (140 kWh/(m^{2}a)) and 27% of new home built with 2000 building regulation (59 kWh/(m^{2}a)).

The analysis of costs for a 6-plot terrace shows that additional cost from traditional building would be £325.000. The 90% of this increased cost is relative to the cost of glazing, in particular due to the fact that BedZED dwelling has four times more glazed surface that a traditional building, most of it on south façade.

The increased cost for insulation and thermal mass in only the 10% and if the glazing would be reduced to a traditional percentage the additional build cost would decrease to £72.000. However the sunspace glazing on the south façade is a key principle for ZED houses since it provides free heat from passive solar gain, and it reduces electricity demands for 30%.

In addition the added value to the properties from south façades sunspaces and good daylight design is considerable since residents suggest that “one of the main reasons why they bought ZED homes was the sun space and feeling of internal spaciousness that good daylight creates”.

The drastic reduction of space heating that eliminates the need for central heating supply systems, and the reduction of need of hot water to 43% makes it realistic to consider small scale on site generation. Biomass CHP plant, fed with wood chips, was chosen for the advantage of producing simultaneously electricity and heat. This choice was influenced by the availability of an ample tree surgery waste, that otherwise would be landfilled or burn.

The fact that the CHP would not be used for space heating, since it is not needed, but only for warming water is really important for the efficiency of the system. Fluctuant seasonal building heating demand in fact would have difficultly matched with CHP constant production. Domestic hot water instead has total daily demands relatively constant along the year, so it's enough to design heat storages that can satisfy the fluctuation of water demand along the day.

The CHP system generates the total amount of electricity needed in BedZED. It generates 726.000kWh/a of electricity and 1.452.000 kWh/a of heat. This heat will not be used only to heat water but also to dry the wood chips. It's estimated that will be produced around 400.000 kWh/a of hot water.

The cost of the CHP plant is £389.000 plus additional £182.000 for distribution and £59.120 of annual running cost saving 388t/a of CO_2 of which 312t/a for electricity and 76t/a for hot water.

The choice of installing photovoltaic was considered only after deciding to invest in electric cars. In this perspective the payback reduced to 13 years, 6,5years considering the 50% EU/UK grants for photovoltaic investment, turning the investment interesting. Initially, before considering electric cars, photovoltaic was discarded because the payback of the investment would have been too high, 75 years compared to the 20 years life of panels.

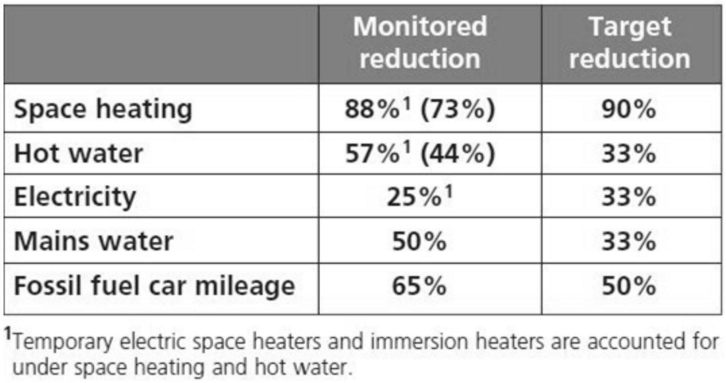
This reduction of payback period is due to the fact that electricity for cars would be used to substitute petrol that have higher price. This turned the investment convenient. For this reason finally in BedZED have been installed 777m^2 of photovoltaic panels that produce 108.000kWh/a of electricity, enough to supply 40 electric cars, displacing 46t/a of CO_2.

3.4.1.4 **Measurable results**

Building a 6-plot terrace with BedZED specifications cost a predicted extra £685.127 however the planning gain allow the developer to generate an extra profit of £208.800 and the added value for spacious dwelling with sky gardens combined with the attraction of significant bill savings have a potential added value of £480.000.

The monitoring of the consumption BedZED has shown reduction in space heating of 88%, thanks to the passive strategies, 57% in hot water, 25% in electricity and 65% in travel distance by car. The monitored reduction reflects the targets reduction initially fixed (table 3).

Table 3: Comparison of the monitored reduction with the initial target reduction (Lazarus 2003)



	Monitored reduction	Target reduction
Space heating	88%[1] (73%)	90%
Hot water	57%[1] (44%)	33%
Electricity	25%[1]	33%
Mains water	50%	33%
Fossil fuel car mileage	65%	50%

[1] Temporary electric space heaters and immersion heaters are accounted for under space heating and hot water.

BedZED shows also outstanding results in reduction of car ownership. In June 2003 the car ownership was of 0,61 per household compared to 1,2 between Surrey residents, 0,9 in London and the national average of 1,0.This shows a reduction of 32-50% compared to the custom.

The example of BedZED shows how with clever planning remarkable results can be achieved in reducing consumption without compromising the return on investment and obtaining an added value that can help the selling of the dwellings. Investment on sustainable neighborhoods therefore is not precluded to private investors.

3.4.2 **VAUBAN**

Vauban is a mixed use neighborhood of 38 hectares, with 5000 residents and 600 working places, developed by municipal authority of Freiburg on the land previously occupied by a French army barrack. The city of Freiburg bought the land after the barrack was dismantled in 1992 and started the planning in 1993. The construction was completed in 2006 after three development phases (Vauban.de 2013).

Figure 21: Picture of a car free street in Vauban (PATERSON 2009)

The mission of this urban development is to implement a city district in a cooperative participatory way with the aim of meeting ecological, social, economic and cultural requirements. This participation between public authorities and residents is one of the biggest strength of the project, making the residents conscious and favors social cohesion, community relations, and adherence to ecological lifestyle.

Fundamental in this process of participation was the role of Forum Vauban, a NGO organization representative of people's needs and a support to their initiatives. The participation went far beyond the legal requirements and enabled people to participate in the planning process. It is in fact from the Forum discussion that some of the key features of the development as parking free concept, the wood chips fuelled cogeneration plant and the abundance of passive houses were born (Kasioumi 2011).

3.4.2.1 **Urban design**

Vauban is a high density, 145 inhabitants/ha, mixed use neighborhood designed as a district of short distances with schools, kinder gardens, farmer's market, shops, recreational areas and around 600 jobs at walking/cycling distance, in order to privilege the car free living.

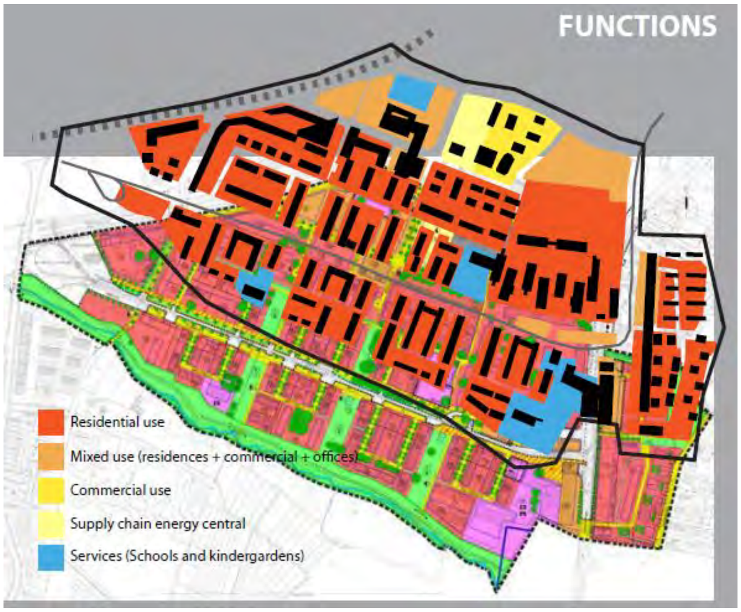


Figure 22: Distribution of uses in Vauban (Leoni & Dematteis 2010)

The functions are distributed and integrated in the road network that plays a very fundamental role in relation to sustainability. The roads are hierarchized with different speeds limitation that never exceeds 30km/h inside the neighborhood, and parking is prohibited in proximity of dwellings.

Community parking spaces are located at the boundaries of residential area. This allows the road to assume a new role that goes far beyond car mobility and become a space of sociability. Streets become playground for kids and spaces for social interactions and safe for walking and cycling (fig. 23).

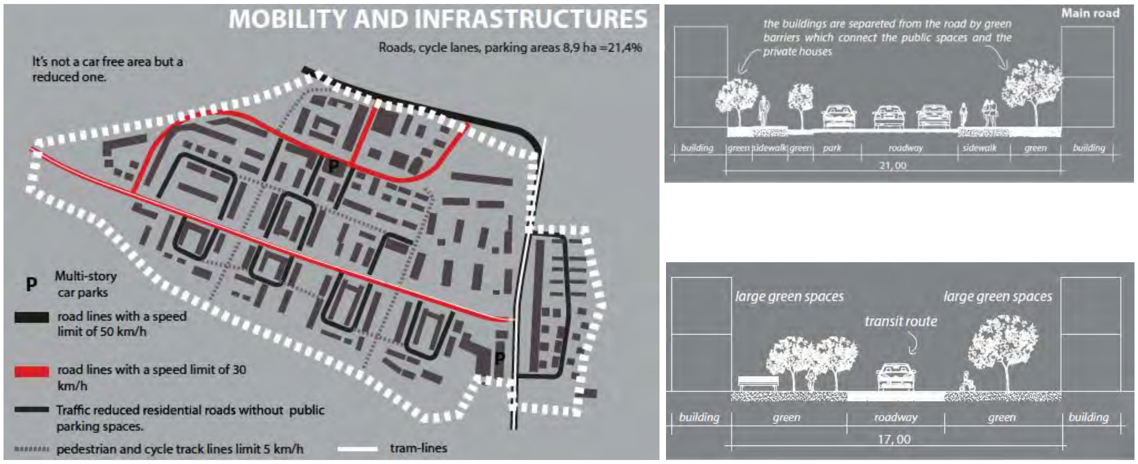


Figure 23: Street Hierarchy in Vauban (Leoni & Dematteis 2010)

The continuity of the open spaces is guaranteed through enjoyable routes and roads reducing significantly their barrier effect. The streets, thus permeable and easy to cross, become safer and favor social interaction. In addition to two main public squares, one of them with the main market, that are the fulcrum of the life of the neighborhood, continuous green open spaces permeate the entire neighborhood offering recreational areas, playgrounds, and helping to mitigate and refresh the air (fig. 24).

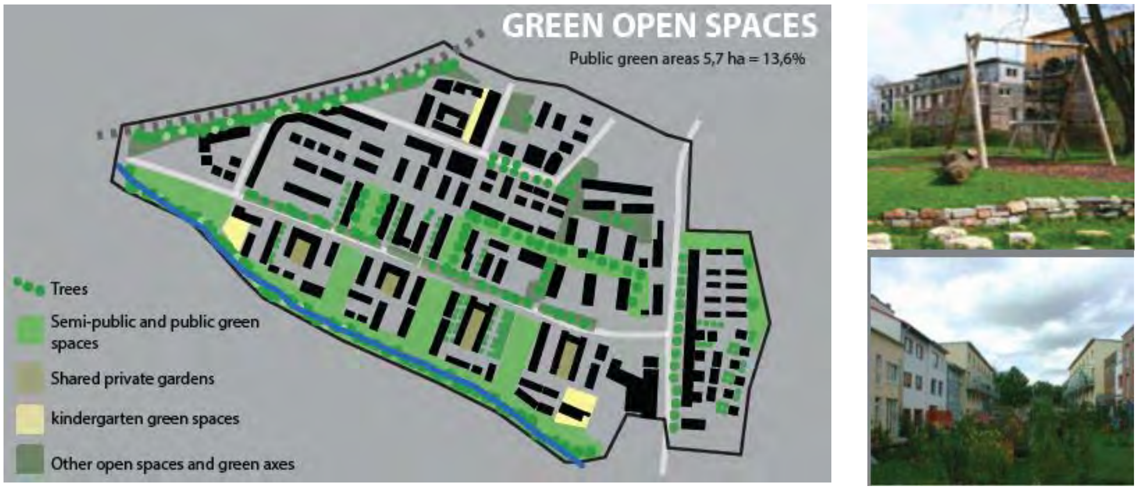


Figure 24: Green open spaces in Vauban (Leoni & Dematteis 2010)

To further reduce the need to use car two bus lines connect Vauban to the downtown. The public transport was significantly improved in 2003 with a tramline crossing the neighborhood.

The need of car ownership was reduced making available a car-sharing company. To promote car-sharing the participation offers special discounts in the use of public transport. Participants have the right to a year free pass for the busses, and 50% discount on train ticket.

3.4.2.2 Energy

The objective of the development is to create a low energy neighborhood where high percentage of the energy needs is satisfied by renewable energy production. To reach it passive solutions have an important role in the design of Vauban where all the buildings must be built with improved low energy standards with maximum consumption of 65kWh/(m^2a) compared with the usual consumption of older houses of 200kWh/(m^2a), and 100kWh/(m^2a) for houses built between 1995 and 2000 (Vauban.de 2013). These standards are achieved through an increased insulation, more thermal efficient windows, and a correct orientation of building and windows (Kasioumi 2011).

In addition 92 houses meet the passive house standards, consuming less than 15kWh/(m^2a) for space heating, and 10 meet plus energy standard, producing more energy than the amount consumed (Energie-Cités 2008).

The production of the energy still needed, despite the significant reduction implied by the application of low energy standard, is supplied by a cogeneration plant and solar and photovoltaic panels.

The cogeneration plant is powered for 80% by wood-chips that come from trees of the nearby Black Forest and the remaining 20% with natural gas. The CHP plant is estimated to produce 12.000.000kWh/a of heat and 1.700.000kWh/a of electricity (Vauban.de 2013).

Vauban was one of the biggest solar districts in Europe with 1200m^2 of photovoltaic panels with a power of 120kWp, and with 450m^2 of solar collectors producing hot water (Vauban.de 2013).

3.4.2.3 Measurable results

The global investment in Vauban is estimated to be around 500.000.000€ representing only the 3-5% more than the cost for traditional developments (Kasioumi 2011).

The Oko Institut, institute for applied ecology, found that in Vauban energy saving amount to 28GJ/a, corresponding to 7778 kWh/a, and a reduction of CO_2 emission of 2100t/a (Öko Institut 2002).

A survey conducted in the neighborhood in 2002, showed that 70% of the trip in Vauban are done by public transport, or walking and cycling. Only 30% of the trips are covered by car, of which 28% by car owning and 2% by non-car owning (Broaddus 2010).

Another survey in 2009 have shown how in Vauban every 1000 inhabitants there are only 157 cars compared with the 367 in Freiburg and 524 in Baden-Wurtemberg, with a respectively reduction of 57% and 70% in car ownership (Kasioumi 2011).

Demonstration of the vitality of the neighborhood is that a third public kindergarten and the enlargement of the primary school are needed to satisfy the new needs of the residents (Kasioumi 2011).

These two case references suggest possible strategies to deal with nearly zero energy at urban scale and show how the approach at urban scale to reach low energy consumption can obtain outstanding results.

The integration of high thermal insulation and more efficient glazing combined with supply systems based on sustainable resources as cogeneration, solar thermal and photovoltaic allows obtaining significant reduction of energy needs and emission.

They also show how the integration with a clever urban design can enhance remarkable improving. The planning philosophy with the emphasis away from cars, keeping the heart of the neighborhood car free, limiting the speed in the residential part to 30km/h and limiting the parking spaces, locating them around the edge of the site, and simultaneously offering alternatives to private car, efficient public transport and car-sharing can enhance a significant reduction of car use with a consequent decrease of consumption and pollution and increasing the livability of the neighborhood.

This urban design approach allows the inhabitants to accept high densities, 150 inh/ha without compromising the quality of life of the urban area and without conflicting with people’s wish of outdoor recreational green areas close to the residence. These densities in fact are reached without compromise the availability of open spaces and the privacy for the residents.

3.5 REMARKS ABOUT NEARLY ZERO ENERGY APPLIED TO URBAN

What seems evident, both from the discussion of the challenges of nearly zero energy applied to urban areas and from the analysis of the reference neighborhood, is that at urban scale the concept of nearly zero energy is deeply influence from the first stage by urban planning and design.

This indissoluble link between urban design and NZEUA enhances the strength of this new concept. NZEUA could not be only an instrument to achieve low energy consumption, but to be a foundation to provide a platform to promote a sustainable urban development (Koch 2009), strongly claimed by the United Nations (UN 1987).

In fact considering that urban space does not have only a physical nature, but also a socio-economic nature (Schnur & Gebhardt 2008), approaching the question of nearly zero energy at urban scale allows not to influence only consumptions, but simultaneously the socio-economic livability of the area involving the residents in the life of the area and improving the quality of life, as clearly testified by the neighborhoods of Vauban and BedZED.

In this first part of the thesis it has been analyzed the nearly zero energy concept and factors that highlight its extended application to urban zones.

Considering that the main challenge of NZEB is to achieve nearly zero energy but with optimal cost even taking into account only the two factors considered by current trends, the building and system factor, the enlargement of scale shows technical and economical potentialities to reach nearly zero energy, thanks to the availability of different technologies, not suitable implemented in the single building, the homogenization of the consumption patterns and to the economy of scale that the dimension can trigger.

Urban scale furthermore reveals more clearly its whole potentialities when the analysis is broadened, and it is assessed also the impact of urban morphology that strongly impacts not only building but also transport consumption. A potential reduction of 50% of building consumption cannot be underrated particularly considering that is potentially for free. A better design of urban spaces in fact, choosing for example a proper passive ratio, a priori would not imply an increase of cost.

All these reasons suggest a need of a more detailed discussion of the implications of the enlargement of scale from NZEB to NZEUA, in order to quantify the advantages that the new scale can trigger, and its limitations, and to deepen this new link between urban design and consumptions.

4 THE CASE STUDY

After having contextualized the nearly zero energy concept and analyzed the challenges of NZEUA, the aim of this second part of the work is to study its application to a case study. Since the ambit discussed is really ample, it has been decided to focus only on few key aspects of the concept, and in particular, the in depth analysis of the building and system factors.

Even if the extension to urban area is not limited to these factors, the analysis of the case study is restricted to this sphere with the purpose of quantifying the advantages that the urban scale can benefit, in term of performance and cost, when are controlled only the parameters that characterize the traditional approach to NZEB (passive and actives solutions).

The analysis of the case study follows this methodology:

- choice of the case study,
- characterization of the neighborhood,
- typification of the neighborhood,
- estimation of the current consumption,
- choice and implementation of the strategy to reduce the consumption,
- choice and implementation of the strategy to supply on site the energy needed.

It has been decided to discard the hypothesis of designing a new neighborhood and instead looking for an existent neighborhood, which needs refurbishment. This choice has been taken in the awareness that, at least for the EU context, before occupying new lands it is necessary to capitalize on the existing building stock since the land is already strongly urbanized.

In EU in fact approximately 85 millions of people live in residential settlements which were constructed after the Second World War and prior 1990 using standardized construction methods (B.&S.U. 2011), meaning that they have high energy consumption and low energy efficiency.

In addition to this it is important to stress that buildings constructed today will be there for the next 50 to 100 years. For example, 92% of the building stock from 2005 will still be there in 2020 and 75% in 2050. This is due to the very low demolition rates (about 0.5% per year) and new built construction rates (about 1.0% per year) (DG Energy 2012).The strategic role that energetic refurbishment could play is underlined by a BPIE study that estimates that all existing buildings will be refurbished at least once by 2050 (Kaderják 2012).

So the ambitious targets of reducing GHG emission by 88-91% in building sector by 2050 (EC 2011), referred to residential and tertiary sectors, cannot be achieved without a great investment in the refurbishment of existing building stock. That’s why in the ambit of this work it has been chosen to study the application of nearly zero energy to urban zones for a preexistent neighborhood that needs to be refurbished.

After having chosen the case study and done its characterization it is necessary to proceed with the estimation of its current consumption.

However, before doing this, it is necessary to typify the neighborhood, classifying the building stock. A neighborhood in fact can be constituted by hundreds of buildings and so it is unthinkable to simulate every single building to determine the total consumption. To simplify the calculation it is necessary to group the buildings in few typologies that are distinguished by common characteristics, thus suggesting equivalent consumption, and consequently extend the results for all the buildings.

Once typified the neighborhood is then possible to proceed to the estimation of the annual consumption needed to keep the comfort condition for the different typologies, and from these values can be extrapolated the estimation of the whole neighborhood consumption.

Knowing the current consumption it is then possible to study some strategies, firstly to reduce the consumption, through passive solutions, and secondly to produce from renewable on-site energies a significant share of the energy still needed.

Beyond the quantification of the improvements obtained through the refurbishment, the purpose of the analysis is to observe the advantages in term of feasibility of the investment that arise when clustering a group of buildings. The aim is to verify if the clustering can be a challenge to achieve the feasibility of solutions that can be not economically advantageous for the single building.

4.1 MIRA SINTRA: A SUSTAINABLE NEIGHBORHOOD

The neighborhood chosen for the analysis is the neighborhood of Mira Sintra, in the municipality of Sintra.

There are two main reasons that support this choice. Firstly this neighborhood was built in 1965 and therefore its buildings suffer from low thermal properties, not being insulated, and need to be refurbished for their ages. Secondly being in prefabricated concrete, despite the significant extension of around 42 hectares, the buildings can be easily typified in few typologies with common characteristics.

Figure 25: Location of Sintra relative to Lisbon (base source: Google maps)

This choice furthermore has been taken due to the interest revealed by AMES, the energy agency of Sintra, in the study of an energetic refurbishment strategy for this neighborhood. This interest to turn Mira Sintra in a sustainable neighborhood is not a new initiative, but it is in continuity with the pilot project "Mira Sintra, um bairro sustentavel "started in 2007(Mira Sintra, a sustainable neighborhood) (AMES 2011) that is claimed to be extended to the entire neighborhood.

This pilot project was born with the purpose of:

- Increasing the quality of life of the residents in the present and future,
- Reducing the cost of energy,
- Requalifying the thermal, acoustic and environmental comfort of the neighborhood,
- Favoring a sustainable development of the neighborhood,
- Recognition and valorization of the neighborhood,
- Turning the residents proud of living in the neighborhood.

The study on the potentialities of the energetic refurbishment conducted in this thesis is set in continuity with the purpose of the study "Mira Sintra um Bairro Sustentável".

4.1.1 THE FREGUESIA OF MIRA SINTRA

The neighborhood belongs to the Freguesia of Mira Sintra, whose name derives from its dominant position with a panoramic view on the Serra de Sintra. Created in 2001 it resulted from the splitting of Freguesia de Agualva- Cacém, in four new Freguesias: Mira Sintra, S. Marcos, Agualva e Cacém.

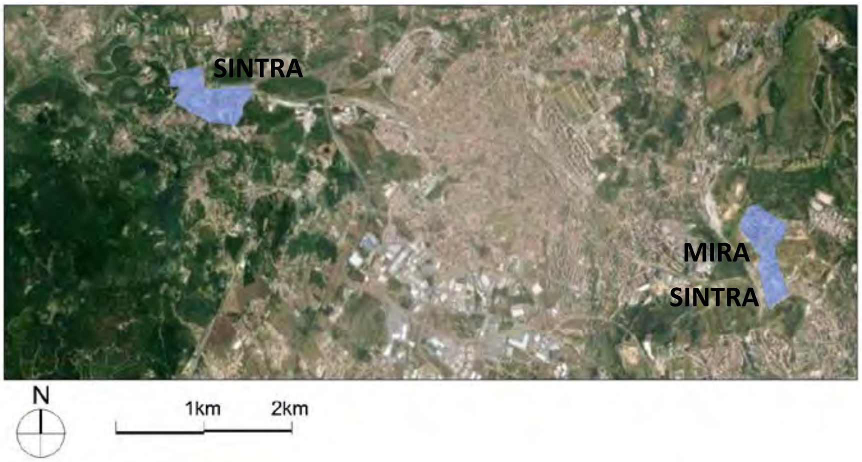


Figure 26: Location of Mira Sintra relative to Sintra (base source: Google maps)

The Freguesia is located in the East part of the municipality of Sintra, in the metropolitan area of Lisbon and occupies a surface of around 100ha. The census of 2011 (CSFMS 2012) revealed that the population of the Freguesia is of 5280 inhabitants. It is characterized by an old population with around 30% over 65 years, higher than the municipal and Portuguese share that are respectively 13,83% and 19,15%. From 2001 Mira Sintra lost around 23% of population, with the highest decrease in the group between 25 and 64 years.

Table 4 Population in Mira Sintra (CSFMS 2012)

Age groups	M	W	Total 2011	Total 2001	Diff	Var (%)
0-14 years	361	342	703	814	-111	-13,6%
15-24 years	261	270	531	959	-428	-44,6%
25-64 years	1172	1286	2458	4375	-1917	-43,8%
> 64 years	728	860	1588	698	890	127,5%
total	2522	2758	5280	6846	-1566	-22,9%

In the Freguesia live 2059 families, with a predominance of families composed by two residents, with a high number of families with only one resident. The average family is composed by 2,56 persons.

4.1.2 CHARACTERIZATION OF THE NEIGHBORHOOD MIRA SINTRA

Built in 1965 by the Direcção Geral dos Edifícios e Monumentos Nacionais / Serviço de Habitações Económicas, it is a social housing neighborhood designed following principles of the Athens chart and modernist cities, with a preponderance of common apartment blocks with a good solar exposition and spacing between buildings to guarantee the natural ventilation (AMES 2012).

The neighborhood extends on an area of approximately 42 hectares and accommodate 4677 inhabitants (INE 2011), with a population density of 111,36inh/ha. Of the 2109 apartments available around 15% are empty. The percentage of empty apartment is lower both than in the municipality of Sintra (21%) and in the municipality of Lisbon (23%) (INE 2011).

Table 5: Urban characterization of the neighborhood[1]

Neighborhood Mira Sintra			
Land surface area (ha)	42ha		
Population (inh)	4677 (source: INE 2011)	Pop density (inh/ha)	111,36
Number of families	1800 (source: INE 2011)	Average family (inh/fam)	2,60
Number of apartments	2109 (source: INE 2011)	Empty apartments[2] (%)	14,65
Lot coverage (m^2)	60106	Lot coverage ratio	0,14
Open space area (m^2)	359.894	Open space ratio	0,86
Gross floor area (m^2)	232.223	Gross floor area ratio	0,55

The predominance of multi-family buildings in the neighborhood allows a medium-high density development (Nunes da Silva 2011) with 50 apartments per hectare without compromising the availability of open spaces, which cover the 86% of the land playing a predominant role in the neighborhood.

Great emphasis is given to the landscape design that is the result of the work of the architect Gonçalo Ribeiro Telles, who designed also the Gulbenkian garden and in April 2013 received the Sir Geoffrey Jellicoe's price, the most important price in landscape design.

Along the neighborhood, in addition to the residential buildings, are distributed local facilities and shops to satisfy the daily needs (fig. 27). The neighborhood provides a primary and a secondary school, a church, a market, a supermarket and a public swimming pool. To these in the last years were added the train station of Mira Sintra–Meleças, the day center for the elderlies, the requalification of the urban park and green spaces, the construction of the cultural center and the

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[1] Detailed information on the values characterizing the neighborhood in the annex 1

[2] The percentage of empty apartments is calculated considering that the number of apartments available correspond to the maximum number of families that can be collocated in the area.

reconstruction of the Mill Stone (Moinho da Pedra) improving the quality of life of the population of Mira Sintra.

In addition to these bigger facilities, local shops are distributed all over the Freguesia in the ground floor of the multi apartment blocks.

The reduction of population that characterized Mira Sintra between 2001 and 2011 therefore do not seem a consequence of lack of services and local facilities, but probably is due to a lack of work in the surrounding area. This consideration is suggested by the fact that the highest decrease occurred in the group between 25 and 64 years.

4.1.3 CHARACTERIZATION OF THE BUILDING STOCK

All the residential dwellings are built with heavy concrete prefabrication, with the skeleton executed on the spot. The modules of concrete were executed in the factory with the vain already defined. The prefabrication guaranteed fast execution, however the thermal characteristics of the envelope are below of an acceptable limit to guarantee thermal comfort with low energy consumption (AMES 2007).

Within the residential buildings can be clearly individuated three typo morphologic units distinguished by common features that suggest that the buildings of the same typology could be characterized by comparable consumptions. The 3 typologies can be subdivided in sub classes (fig. 27) that, maintaining common characteristics, differ in dimension (Gross Floor Area) and have different configuration of the openings in the façades.

Figure 27: Characterization of the building stock of the neighborhood Mira Sintra (Base source: Google maps)

4.1.3.1 **Typology A**

This is the prevailing typology composed by 160 multi-family dwellings in row. The building has 5 residential floors with two apartments for each floor on the sides of a common stair, which is in the middle of the main façade. The ground floor is sometimes occupied by garages, other times by shops and bars.

Typology A can be subdivided in 2 sub classes A1 and A2 (table 6) that differ for dimension, with A2 with a bigger lot coverage than A1.The two sub classes differ alsofor openings on the façades, with different percentage of glazing surface and windows size (fig. 28).

Figure 28: Typology A. Sub-classes A1 on the left and A2 on the right.

Table 6: Quantification of the typology A

Sub class	Lot coverage area (m^2)	N apartments	N buildings	Total N apartments
A1	153,5	10	60	600
A2	192,9	10	100	1000

4.1.3.2 **Typology B**

This typology is characterized by 10 multi-family towers with cross plant and 9 residential floors. Every floor has 4 apartments served by central common stair and elevators. The ground floor is sometimes occupied by garages, other times by shops and bars.

Typology B can be subdivided in 2 sub classes B1 and B2 that differ for dimension, with B2 with a bigger lot coverage than B1 (table 7). The two sub classes differ also for openings on the façades, with different percentage of glazing surface and windows size (fig. 29).

Figure 29: Typology B. Sub-classes B1 on the left and B2 on the right.

Table 7: Quantification of the typology B

Typology	Lot coverage area (m^2)	N apartments	N buildings	Total N of apartments
B1	518,6	36	5	180
B2	588,4	36	5	180

4.1.3.3 **Typology C**

In the neighborhood there is also a minority group of 54 semi-detached houses with two floors.

Figure 30: Typology C

Table 8: Quantification of the typology C

Typology	Lot coverage area (m^2)	N apartments	N buildings	Total N apartments
C	149,6	2	54	108

4.2 CURRENT CONSUMPTION: ENERGY SIMULATION

To estimate the current consumption of the neighborhood instead of using the RCCTE, the Portuguese legislation, it has been chosen to resort to the software Design Builder.

This choice has been taken because this program allows running a dynamic simulation of energy consumption and thermal load of a building through Energy Plus, one of the leader energy simulators program, developed by the US energy department. Being provided of user-friendly interface, this program facilitates the use of Energy Plus through a graphic interface, without compromising the accuracy of the thermal simulation.

4.2.1 GETTING READY FOR THE SIMULATION

Before running the simulation it is necessary to know the geometrical characteristic of the buildings in order to be ready to model the building with Design Builder.

Since it has not been possible to obtain the technical drawings of the buildings, the dimensions of the outline of the external walls, needed to draw the plans, have been estimated through Google maps and confirmed with measurements on the spot. The visits on the spot have been also necessary to understand the geometry of the façades of the buildings. The elevations have been drawn from the analysis of pictures taken and measurement of the windows.

Furthermore it is necessary to set the properties of the building to simulate; the location of the building, in order to do the simulation with the correct climate data; the activity data, to estimate correctly the internal gains; the comfort condition to be maintained and the quantity of hot water required for person.

It’s also necessary to set the material properties composing the building, in order simulated correctly the heat losses and solar gains, and finally to set the characteristics of the supply systems that will provide the energy needed.

4.2.1.1 Location

Since the neighborhood is located in the municipality of Sintra it would be appropriate run the simulation using the climate condition of Sintra. However the climatic data of Sintra are not available within Design Builder, since they are provided only to whom own the license of the program Sol Term provided by LNEG.

Therefore it has been chosen to run the simulation with one of the climate data freely available. The simulation has been run considering the climate data of Coimbra. Despite it could appear a better choice the use of Lisbon weather data, due to its proximity to Sintra, this choice is suggested by the fact that Coimbra winter condition better approximates the weather of Sintra, both considering duration of heating season and degree days. The summer condition in Lisbon would be more suitable to the cooling requirements (table 9).

Given that, how it will be noticed in the analysis of the results of the simulations, the cooling loads are lower than 10% of the heating loads it has been chosen to privilege the winter than the summer conditions.

Table 9: Comparison of the climate of Sintra, Lisbon and Coimbra (RCCTE 2006)

Location	Winter climatic zone	degree K*day (°C)	Duration of heating season (months)	Summer climatic zone	External temperature of the project (°C)	Thermal amplitude (°C)
SINTRA	I1	1430	6	V1	29	8
LISBON	I1	1190	5,3	V2	32	11
COIMBRA	I1	1460	6	V2	33	13

4.2.1.2 Activity data and supply systems

Nevertheless the simulation has been run with Design Builder, the data introduced in the program to run the simulation has been taken by the RCCTE. This choice has been taken in order the results to reflect the peculiarities of the Portuguese habits.

The simulation has been run keeping comfort condition, 20°C in winter and 25°C (RCCTE 2006) in summer, for 365days/year and 24h/day.

The domestic hot water (DHW) consumption is estimated 1,21 l/m^{2}day (table 10) considering an average consumption of 40l/day/person at 60°C and with water supply at an average temperature of 15°C (RCCTE 2006).

Table 10: Estimation of the DHW requirements in the neighborhood

Place	Av family (inh/family)	N apartment	Max pop (inh)	DHW (l/day)	Neighborhood total net floor area[3] (m^2)	DHW (l/m^{2}day)
Mira Sintra	2,60	2068	5377[4]	215072	177937	1,21

The internal gains due to occupation, metabolic gains, lighting and household equipment are considered 4W/m^2 (RCCTE 2006).

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[3] Calculated considering the typification of the building stock (annex 3)

[4] Estimation considering in average 2,6 persons living in each apartment

The buildings of the neighborhood are not provided by central heating and cooling[5], therefore the heating and cooling comfort conditions are guaranteed by electric appliances with and efficiency η=1. The DHW is provided by gas boiler with and efficiency of η=0,5 (RCCTE 2006).

The ground floor of the multi apartment buildings and the stair cases are simulated as unoccupied not conditioned. This choice is due to the fact that ground floors are sometimes occupied by shops and sometimes by garages. Not knowing the consumption it has been preferred not accounting them in the simulation.

4.2.1.3 **Material properties**

Since the exact construction technologies and properties are not know, it has not been possible to trace documents with the specifications of the solutions used in the buildings, it has been chosen from the library of Design Builder the solutions that seem reasonable. The choices have been based on the only information available and that are the fact that the buildings are not insulated, in precast concrete (AMES 2007) with a thickness of the walls of 25 cm, and that the typology A and C have a not insulated unoccupied pitched roof while the typology B has a concrete not insulated flat roof[6].

Here follows the solutions chosen[7]:

- Walls with 25cm concrete block heavy-weight wall with an U value of 3,092W/(m^2°C);
- Floors with 20cm concrete slab with an U value of 2,138 W/(m^2°C);
- Unoccupied pitched roof (typologies A and C) composed by clay tiles and has an U value of 6,061 W/(m^2°C);
- Semi-exposed ceiling under pitched roof (typologies A and C) composed by a concrete slab of 10 cm with an U value of 2,636W/(m^2°C)
- Flat roof (typology B) with 10 cm concrete slab finished with asphalt waterproofing with an U value of 3,793.
- Windows with single glazing with a U value of 5W/(m^2°C)[8]

The U values of the solutions proposed are correctly much higher than the maximum values allowed by the Portuguese regulation since the buildings date back to 1965 and were designed without thermal insulation. The maximum thermal values specified by the RCCTE are set to 1,8W/(m^2K) for vertical and 1,25W/(m^2K) for horizontal opaque surfaces in contact with the exterior.

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[5] Information extrapolated by interviews with the residents

[6] Information obtained through visits and measurements on the spot.

[7] More detailed information about the solution chosen are in the annex 2

[8] U value averaged between glazing and window frame basing on the value suggested by ENEA (2013)

The infiltration rate has been calculated 1,05ac/h, following the RCCTE (2006) and considering an exposition class of 2 with windows with rolling shadings and without any classification of permeability to the air according to the norm EN12207.

The rolling shadings, in the simulation, are kept close when the outside temperature is higher than 26°C. This choice has been taken to account the positive effect of the shadings to reduce overheating in the hotter periods.

4.2.2 **THE CURRENT CONSUMPTION**

Since at neighborhood level we are in presence of hundreds of buildings, once decided the parameters to run the simulation, it's necessary to decide which buildings should be considered as references for the extrapolation of the whole consumption. The number of buildings chosen is crucial since this choice determines the time that will be needed to obtain the results of the simulations.

Even once classified the buildings in typo morphologic units, the number of possible combinations between floor areas, percentage of glazing of the façades and orientation of the buildings, that would determine variations in consumption, is too high to simulate exhaustively all the possible combinations. This is even clearer considering that, beyond the simulation to obtain the current consumption, for each configuration chosen later should be run many simulations to quantify the effect of each energetic refurbishment solution proposed.

Even if the case of Mira Sintra, where all the buildings can be clearly classified in three typologies, it would be impossible to analyze exhaustively all the combinations[9].

It has been therefore decided to compare the results of the simulations for the more common configurations to understand which combinations better represent the whole neighborhood.

In the range of possibilities it has been chosen a few ones that seem to represent better the neighborhood, and through them has been estimated the consumption of the neighborhood and measured the consumption reduction due to the energetic refurbishment.

The typology A, besides the two sub classes A1 and A2, presents 4 different orientations, North South and rotated 42°, 48° and 180° from the N/S orientation (fig. 31).

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[9] The details on the typification of the building stock, different combinations, and models used to simulate the different typologies are in the annex 3

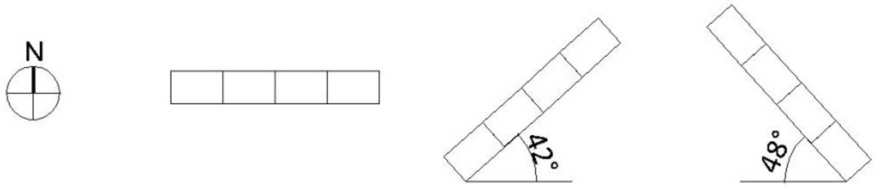

Figure 31: Main orientations typology A

The comparison of results of the simulation of different configurations of the typology A (table 11) shows how the variation of the heating loads is low. Due to orientation the maximum variation is of 4,3 % for the typology A2. Similarly the variation between sub classes A1 and A2 are always lower than 3,3%. The cooling loads are mainly influenced by orientation with a maximum variation of 36% for the building A2. Same orientation of the two typologies instead differ of maximum 24,6%.

Despite a variation of 36% is anything but negligible, it has to be noticed that cooling load are responsible for less than the 10% of the total energy needed. Therefore such variation in cooling loads is not so substantial in the total consumption.

Table 11: Results of the simulation run with Design Builder of different configurations of the typology A

		Typology A			Typology A		
		A1	A2		A1	A2	
		Heating			Cooling		
		kWh/(m^{2}a)		Variation (%)	kWh/(m^{2}a)		Variation (%)
Orientation	N/S	73,2	74,6	2,0%	5,1	6,5	21,2%
	rot 42°	75,1	77,2	2,7%	6,9	9,2	24,6%
	rot -48°	75,6	77,9	2,9%	6,6	8,5	22,5%
	rot 180°	75,4	78,0	3,3%	4,7	5,9	20,1%
Variation (%)		3,3%	4,3%		32%	36%	

The maximum variation of consumption (heating+ cooling) between the different configurations is of 10% achieved between the building unit A2 rotated 48°, with the highest consumption of 86,4kWh/(m^{2}a), and the unit A1 N/S, with the lowest consumption of 78,3kWh/(m^{2}a).

As reference to represent the typology A has been chosen the building A1 with anti-clockwise rotation of 42° relative to North/South orientation, since it shows average values for the typology. The current consumption of this typology are therefore 75,1kWh/(m^{2}a) for heating and 6,9kWh/(m^{2}a) for cooling. This building unit consumption differ of maximum 5,4% from the lowest and highest consumption (heating +cooling) of the typology A.

Similar consideration can be done considering the consumption of the typologies B and C due to their different configurations (fig. 32).

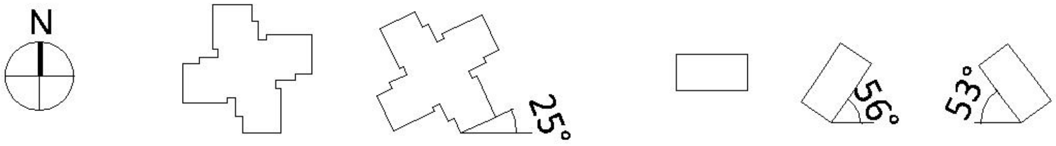

Figure 32: Main orientations typologies B and C

These typologies show even lower variations with a maximum of 2,2% for heating and 6,7% for cooling for typology B and 2,31% and 15,54% for typology C[10].

Considering the accumulated consumptions (heating+ cooling) the variation between the configuration chosen (table 12) and the others is of maximum 3,9% for the typology C and 2,7% for the typology B.

Choosing the building B1 and C with orientation N/S as references for the whole typology, the neighborhood would be characterized by the following consumptions:

Table 12: Recapitulation of the current consumption obtained with Design Builder of the buildings chosen to represent the entire neighborhood

		Typology		
		A	B	C
Heating	kWh/(m^{2}a)	75,14	88,16	98,62
Cooling		6,94	7,29	11,13

4.3 ENERGETIC REFURBISHMENT

Knowing the current consumptions of the different typologies it has been proceeded to the proposal of different solutions, firstly to reduce the current consumption, improving the envelope thermal properties of the buildings, and secondly to supply from renewable sources the remaining energy required.

In the ambit of the thesis it will be discussed only the implementation to the building typology A, which is the one predominant in the neighborhood. The same considerations could be applied to the typologies B and C to investigate exhaustively the neighborhood.

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[10] Drawings and results of the simulations are in the annex 3

4.3.1 **THE TYPOLOGY A**

As shown previously, it has been chosen the sub class A1 rotated 42° anti-clockwise from the orientation N/S since it's the one that shows average consumptions for the typology A. In the following of the thesis when talking about the typology A we will always refer to the building unit A1 chosen as its reference.

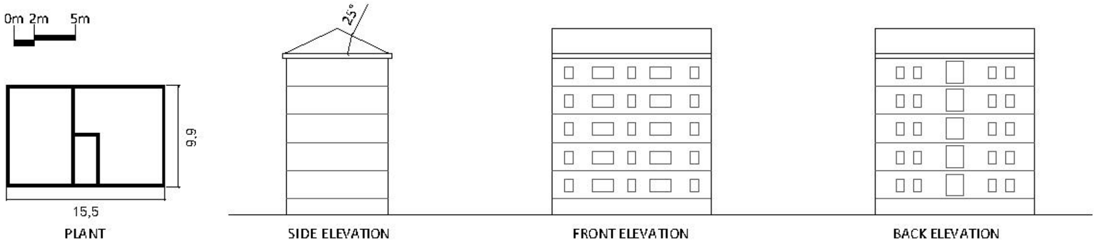

Figure 33: Representation of the building unit A1 used for the energetic simulation

Since typology A is a multi-family building in row, the simulation has been run considering two models, one for the central unit, between two others units, and one for the edges of the block (fig. 34). This choice is suggested by the fact that the unit at the edges and the central one differs in consumption since the one at the edges suffers of a higher exposition to the exterior conditions, having an higher exterior wall surface.

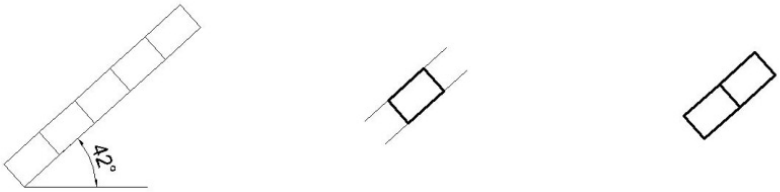

Figure 34: Central and edges units to run the simulation

The neighborhood, following this typification is therefore characterized by 160 building units A with the following characteristics:

Table 13: Characterization of the typology A

Typ	Lot coverage area (m^2)	Net floor area (m^2)	N floor	N building units
A	153,5	126,65	5	160

4.3.2 ANALYSIS OF THE CURRENT CONSUMPTION

In this section are presented the detailed results obtained for the edges unit, analogous consideration can be done for the central unit whose detailed results can be found in the annex 4.

The results of the simulation for the edge unit shows that the building consumes 75,1kWh/(m^2a) for heating 6,9kWh/(m^2a) for cooling of electricity and 47,8kWh/(m^2a) of natural gas for domestic hot water.

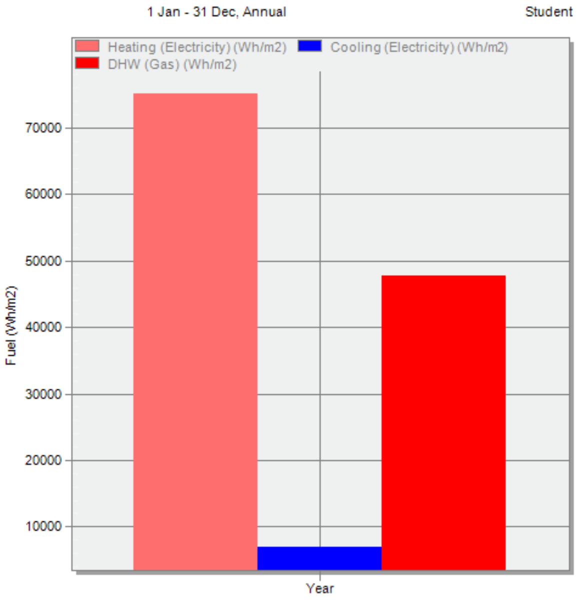

Figure 35: Annual fuel breakdown to maintain comfort conditions of the edge unit (source: Design Builder)

Before choosing where to intervene it is necessary to understand which the causes responsible for the consumption are. This is crucial in order to intervene surgically without wasting uselessly time and resources and to propose effective refurbishment solutions.

It’s important to observe that the heating loads are mainly result of the heat losses through the external surfaces and through ventilation, while the cooling loads are mainly caused by excessive solar gains.

Concerning the heating requirements the result of the winter heat balance (fig. 36) shows how losses through external walls and due to air infiltration are responsible for a high percentage of all losses, respectively 43,5kWh/m^2 and 36kWh/m^2. Windows have lower impact on heat losses 7,5kWh/m^2, due to the fact that, despite the U value really high 5W/m^{2}°C, the building has a low percentage of glazing which covers only the 8,3% of the walls. The semi exposed ceiling under the pitched roof and ground floor are respectively responsible for 7,42kWh/m^2 and 3,2kWh/m^2 of losses.

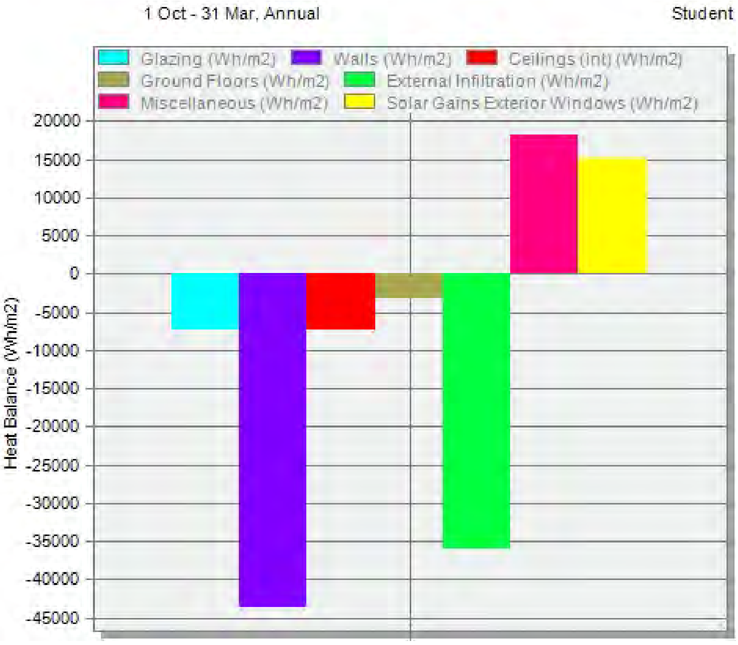

Figure 36 : Winter heat balance (source: Design Builder)

Concerning the cooling requirement it is clear instead that it is caused by solar gains through windows, 17,3kWh/m^2 and internal gains due to due to lighting, equipment and occupation (miscellaneous) that are responsible for 18,2kWh/m^2. The last floor ceiling is also responsible for heat gains, 6kWh/m^2 due to the great exposition of the roof to direct solar irradiation (fig. 37).

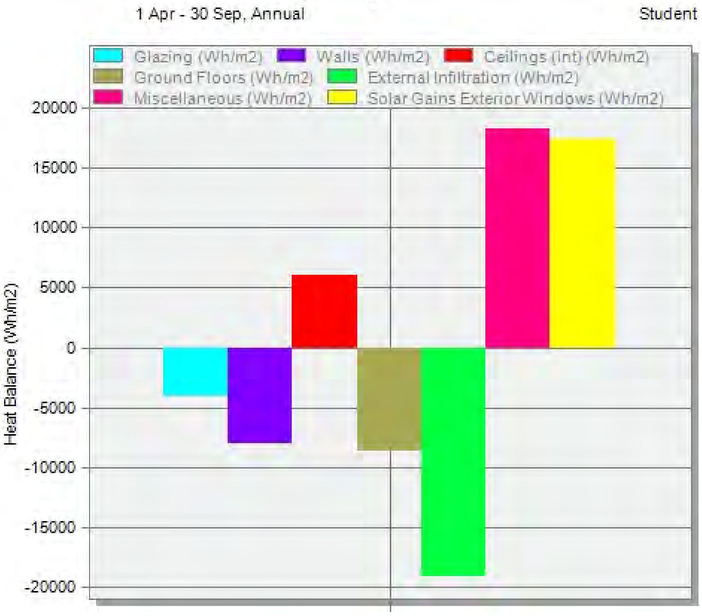

Figure 37: Summer heat balance (source: Design Builder)

It appears clear that to reduce heating consumption it is necessary to reduce losses through the walls and through air infiltration. It is therefore needed to improve the thermal insulation of the external walls, and to substitute the windows frames that are the main responsible for the excessive air infiltration (RCCTE 2006).

Nevertheless the losses through the glazing are not predominant, once changing the windows it is proper to substitute the single glazing with double glazing to reduce the glazing U value.

Finally, even if the results seem to suggest that the roof does not have a main contribution concerning the heating and cooling loads individually, however its loads are counterproductive both in summer and winter, so it has been decided to evaluate also the effect of the insulation of the roof.

There are other two main reasons that suggest that the roof insulation could imply interesting advantages. Firstly because the results are summarized for the whole building, therefore the effect of the roof is averaged on 5 floors, while its effect influences the consumption and comfort only of the last floor. Residents of the last floor therefore would greatly benefit in term of comfort and consumption from roof insulation.

Secondly because having an unoccupied space between pitched roof and last floor ceiling the cost of implementation of the insulation should be really low suggesting a good investment return.

For these reasons beyond the external wall insulation, and the substitution of the windows it has been decided to valuate also the possibility of insulating the semi-exposed ceilings below the pitched roof. It has not been considered the opportunity of insulating the ground floor because the benefit cooling that ground floor determines in summer offset the negative losses in winter.

All the solutions proposed will be discussed in term of consumption reduction, and investment return, believing that the energy improvements cannot be evaluated separately to the feasibility of the investment.

4.3.3 THE BUILDING: PASSIVE SOLUTIONS

4.3.3.1 The external wall insulation: ETICS

As insulation of the external wall it has been opted for an external insulation composite system (ETICS). This choice has been considered to be the best option for refurbishment since it is easy to implement in a preexistent building, being applied to the exterior surface, and because is the solution that minimize the thermal bridges.

The solution proposed is the Weber.term ETICS [11] with 6 cm of EPS with a thermal conductivity of 0,036 W/(m°C). This system has been chosen to be a good compromise between cost 66,06 €/m2

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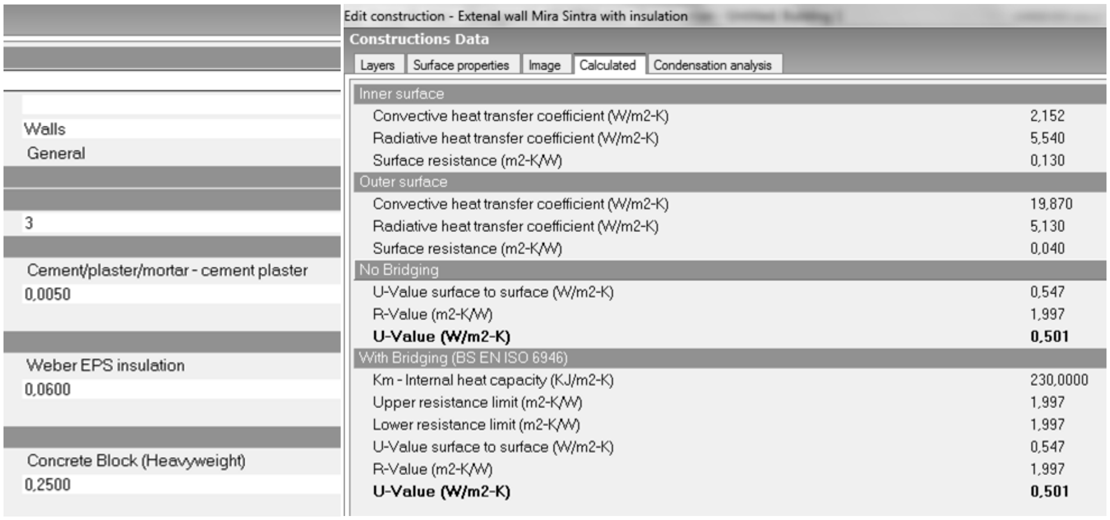
[11] Detailed information about all the refurbishment solutions are in the annex 5

without VAT (CYPE 2013), and quality guaranteed by a well-known German brand specialized in this sector.

With this solution the U value of the wall improves from 3,092W/(m^2°C) to 0,501W/(m^2°C) (fig. 38), significantly lower than the maximum value allowed by RCCTE 1,8W/(m^2°C).



Walls
General
3
Cement/plaster/mortar - cement plaster
0,0050
Weber EPS insulation
0,0600
Concrete Block (Heavyweight)
0,2500

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2,152
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,040
No Bridging	
U-Value surface to surface (W/m2-K)	0,547
R-Value (m2-K/W)	1,997
U-Value (W/m2-K)	**0,501**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	230,0000
Upper resistance limit (m2-K/W)	1,997
Lower resistance limit (m2-K/W)	1,997
U-Value surface to surface (W/m2-K)	0,547
R-Value (m2-K/W)	1,997
U-Value (W/m2-K)	**0,501**

Figure 38: Thermal characteristics of the external wall after refurbishment (Source: Design Builder)

The result of the simulation with the ETICS (table 14) shows significant reduction of heating consumptions: 46,2% for the edge unit and 43,2% for the central unit. The total consumption needed to keep comfort condition is 46,6kWh/m^2 for the edges and 43,9kWh/m^2 for the central unit. This higher consumption, as the higher benefit in the edges, is due to the higher wall exposition of the edges unit to the exterior thus contributing for a higher share to heat losses.

Table 14: Consumption after refurbishment with the ETICS

Typ.	Position	Loads	Unit	Current consumption	Consumption with 6 cm ETICS	Reduction
A	Edges	Heating	kWh/(m^{2}a)	75,1	40,4	46,2%
		Cooling	kWh/(m^{2}a)	6,9	6,2	10,1%
		Tot	kWh/(m^{2}a)	82,1	46,6	43,2%
	Central	Heating	kWh/(m^{2}a)	63,7	37,5	41,1%
		Cooling	kWh/(m^{2}a)	6,5	6,3	3,1%
		Tot	kWh/(m^{2}a)	70,2	43,9	37,5%

Considering that of the 160 units, 66 are central and 94 are in the edges, the total savings due to the application of the 6cm ETICS is 3211,6MWh/a. With an electricity price of 0,165€/kWh (EEP 2013) excluded VAT, its implementation imply an annual saving of 529.907,7€.

Table 15: Quantification of the savings due to refurbishment with ETICS

Position	Number units	Total floor area (m^2)	Savings (kWh/a)	Savings (MWh/a)	Price electricity (€/kWh)	Annual saving (€/a)
Edge unit	94	59.525,5	2.112.353,9	3211,6	0,165	€ 529.907,7
Central Unit	66	41.794,5	1.099.208,0			

Time payback and the net present value (NPV) are the parameters chosen to evaluate the feasibility of the investment.

The NPV is the current value of an amount of money that will be received in future. Chosen the number of years for which we want quantify the profit (NPV), it gives the quantification of the current value of the profits accumulated in all the operation years.

$$NPV\ (i, N) = \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t}$$

with i = discount rate and CF_t the cash flow of the year t and N the life of the investment.

The time payback represents the number of years after which the investment is recovered, the saving of all the followings years are earnings.

Payback = n when $\sum_{t=0}^{n} \frac{CF_t}{(1+i)^t}=0$

To evaluate the feasibility beyond the annual savings it is necessary to estimate the initial investment and the operation and maintenance costs (O&M). As discount rate (i), that represents the risk of the investment, it has been chosen a value of 5%.

Resorting to the generator of price http://www.geradordeprecos.info/ (CYPE 2013), which takes into account the specific characteristics of the construction work highlighting the reduction of unit price due to a bulky purchase, it has been valuated the purchase price of the ETICS with the price of a single building unit, or for all the buildings of typology A of the neighborhood.

Table 16: Quantification of wall surface typology A

Position	Wall surface (m^2)	Implementation cost (€/m^2) (CYPE 2013)	10 years M&O (€/m^2) (CYPE 2013)
Edge unit	498,25	€ 66,06	€ 3,31
Central Unit	350,5		
Tot neighborhood	69968,5	€ 53,21	€ 2,66
Price reduction		19,5%	19,6%

Table 17: Feasibility of the external walls insulation

With the prices of:	Implementation cost (€)	10 years O&M (€)	Payback (years)	NPV (€)
Building scale	€4.622.119	€231.595,7	12-13	3.294.395
Tot neighborhood	€3.723.024	€186.166	8-9	4.238.552
Variation (%)	-19,5%	-19,6%	-30%	+28%

The results (table 17) show a reduction of 19,5% of acquisition price including the installation, and an analogous reduction in the O&M cost.

With the discounted prices the total investment would amount to 3.723.024€ and a 10 years O&M of 186.166 €. Benefitting of the discount due to the scale the time payback is between 8-9 years while with the price for the single unit would be 12-13 years[12].

Considering the design life of the Weber ETICS of 30 years, if correctly maintained (NSAI 2009), the ETICS solution is feasible both with discounted and normal price being the ratio between design life and payback is in both cases higher than 2 and respectively 3,3 and 2,3. This means than for more than half of the operation life it would induce earnings.

The advantage of the scale is clear considering the NPV, in the 30 years life the reduction of consumption would generate a NPV of 4.238.552€ with an profit higher than the initial investment. The NPV would be 3.294.395€ without benefit from the discount triggered by the scale.

4.3.3.2 Substitution of the windows: double glazing[13]

After reducing heat losses through the opaque walls it seems important to reduce air infiltration that is responsible for a high percentage of heat losses and that according to the RCCTE calculation is 1,05ac/h due to the characteristic of the building and of the installed windows.

To reduce this component it has been chosen a window frame "VEKA" in PVC with U= 1,3W/(m²°C) and class 4 of permeability of air according to EN 12207. The new windows frames have been combined with a double glazing with U=3 W/(m²°C) and solar factor of 77%(CYPE 2013).

Due to the reduction of the air infiltration that thanks to the new frames has been reduced to 0,85ac/h (RCCTE 2006), combined with the improved transmittance of the windows, the new

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[12] Detailed calculation of the NPV and time payback are annex 8

[13] In this section are given only a brief discussion of the substitution of the windows and a summary of the results. The quantification of windows typologies is in annex 5 and their costs in annex 2.

windows determine a reduction of 948.662 kWh, that correspond to a reduction of 12% of total consumptions.

To this reduction corresponds annual saving for 156.529€ of electricity.

The financial feasibility of the solution has been calculated considering a nominal life of 30 years for the PVC windows (JMK 2013) and considering 5% discount rate.

Table 18: Feasibility of the substitution of the windows

With the prices of:	Implementation cost (€)	10 years O&M (€)	Payback (years)	NPV (€)
Building scale	€2.029.269	€211.595	25-26	€ 167.319,9
Tot neighborhood	€1.549.982	€ 160.236	14-15	€ 697.493,3
Variation (%)	-23,6%	-24,3%	-42%	+317%

The results shows that with the prices of a single building the investment is not interesting, the price of the windows is too high compared with the energy reduction involved, being the time payback 25-26 years compared to a life of around 30 years.

When assessing the economy of scale instead, the substitution of the windows becomes more interesting. The time payback reduces to 14-15 years, being 2 the ratio between nominal life and payback.

For the substitution of the windows appears clear the advantage introduced by the scale, since an investment that would have not been interesting become feasible thanks to the discount obtained due to the scale.

4.3.3.3 **Insulation of the pitched roof**

Finally it has been assessed the effect of insulating the pitched roof. The solution proposedis a 10 cm KNAUF insulation in mineral wool with a thermal conductivity of 0,04W/(m°C) (CYPE 2013), to be applied above the ceiling of the last floor. This reduces the U value of the last floor ceiling from 2,636W/(m2°C) to 0,347W/(m^2°C).

The improvement of the thermal transmittance of the semi-exposed ceiling determines a reduction of 666.394,5 kWh, corresponding to a reduction of 8,5% of total consumptions, and 109.955€ of electricity annual saving . This saving is huge considering that the losses and gains through the roof affect only the last of the five floors.

The financial feasibility of the solution has been calculated considering a nominal life of 30 years for the mineral wool insulation (ASI 2007) and considering a discount rate of 5%.

Table 19: Feasibility of the insulation of the roof

With the prices of:	Implementation cost (€)	10 years O&M (€)	Payback (years)	NPV (€)
Building scale	€ 195.497,6	€ 0,0	1-2	€ 1.494.781,6
Tot neighborhood	€ 142.448,0	€ 0,0	1-2	€ 1.547.831,2
Variation (%)	27,1%			+3,5%

The insulation of the roof reveals itself, for its low implementation cost, a good investment both for the single building price and the discounted price. Since the profit is more than 10 times the initial investment it does not reveal a substantial difference in the implementation of this solution between the normal price and the discounted.

4.3.4 RESULTS OF THE COMPLETE REFURBISHMENT

Since all the solutions proposed reveal to be interesting at the urban scale both for their energy saving potential and considering the investment return, in this section will be discussed the result of the complete refurbishment summing the beneficial effects of ETICS, substitution of glazing and roof insulation.

Table 20: Comparison of the consumption before and after the refurbishment (source Design Builder)

Position	Loads	Current (kWh/(m2a))	After refurbishment (kWh/(m2a))	Reduction (%)
Edges	Heating	75,14	24,31	68%
	Cooling	6,94	5,76	17%
	Tot	82,08	30,06	63%
Central	Heating	63,66	21,56	66%
	Cooling	6,51	5,99	8%
	Tot	70,18	27,55	61%

The results (table 20) show how the solutions proposed reduce significantly the heating demand, while have a lower effect on the cooling demand. However cooling demands are less than 10% of the heating demand and therefore their reduction is not so urgent.

The financial evaluation of the refurbishment shows how the significant reduction of consumption of around 62% can be reached with a payback time of 8-9 years thanks to the economy of scale. The payback is however interesting also without the discount price and is of 11-12.

Table 21: Costs and savings of complete refurbishment of the building typology A in the neighborhood

With prices of:	Implementation cost (€)	10 years O&M (€)	Price electricity (€/kWh)	Savings	
				(kWh/a)	(€/a)
Building scale	€6.846.885,7	€443.190,6	0,165	4.877.874,7	€804.849
Neighborhood scale	€5.415.453,6	€346.352,6	0,165	4.877.874,7	€804.849

Considering that each kWh of electricity consumed in Portugal corresponds to 0,467kgCO_2 (DEFRA 2012) the refurbishment determine a annual saving of 2077,9 tons of CO_2.

4.3.5 CONSUMPTIONS OF THE NEIGHBORHOOD

Before proceeding to the choice of the solutions to supply the energy required to satisfy the needs of the neighborhood, there are still two steps missing.

Firstly the consumption calculated for the typology A does not include the consumption of electricity for lightings and household appliances. This is due to the fact that in the simulation with Design Builder the lightings and electricity consumption for households have been accounted only as internal gain, 4W/m^2, including gains due to occupation as suggested by the RCCTE. The result of the simulation therefore does not account them as electricity consumption.

Secondly, since the neighborhood is not mono functional, but has a mixed-use pattern with local facilities and equipment, it has been considered appropriate to include these consumption in the sizing of the supply systems.

4.3.5.1 Consumption of typology A: lightings and appliances included

To estimate this consumption it has been used the information of the Energetic Matrix of Lisbon (Lisboa E-Nova 2005) that reports the average energy consumption for residential sector in Lisbon.

Considering annual primary energy consumption due to washings machine, lightings and other appliances of 630GWh and a population of 555.00 inhabitants the consumption of electricity per capita is of 1135,2kWh/inh.

Being the net floor area of all 160 building units A 101.320m^2, and considering 3040inh[14] the population allocated in these buildings of the neighborhood Mira Sintra, the consumption of primary energy is 34,06kWh/m^2 for lighting and appliances.

Taking into account that, considering the Portuguese efficiency of producing electricity (RCCTE 2006), 1kWh$_{final}$=3,37kWh$_{primary}$ the consumption of electricity for the typology A due to lightings and appliances is 10,1kWh/m^2.

Adding this consumption to the ones obtained through simulation after refurbishment with Design Builder (table 20) the total consumption has been determined for the typology A (table 22).

Table 22: Residential consumption typology A

Building unit	Position	Consumption (kWh/m^{2}a)	Total net floor area (m^2)	Consumption neighborhood (MWh/a)
A	Edges	40,17	59.525,5	3.964
	Central	37,65	41.794,5	

4.3.5.2 **Including consumption of neighborhood equipment**

To analyze exhaustively the consumption of the neighborhood, in addition to the consumption due to the residential buildings, should be added the consumptions of local services, facilities and public lightings.

Since this information is not completely available, in this work it has been added to the residential consumption only the information that has been supplied by AMES.

Here follows the information available about the consumption of the equipment of the neighborhood.

1) School EB1: 22.000 kWh
2) Cultural center: 80.000 kWh
3) Church : 12.000 kWh
4) Market: 23.600 kWh

Unfortunately it has not been possible to obtain the data of the day center for the elderly, the education center for the disabled people and the swimming pool. Furthermore, is missing the information of public lightings, which seem to be significant when enlarging the scale to urban areas, accounting for about 2% to 3% of total public sector energy consumption (SEAI 2012).

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[14] Population living in buildings A calculated considering a density of 0,03inh/m^2.

The total consumption of the equipment due to the information available is 137,6MWh/a that added to the consumption estimated for the typology A determine a consumption for the neighborhood of 4.101,6MWh/a.

It is with basis on this value that the electricity supply system will be dimensioned in the next section.

4.4 ENERGY SUPPLY RENEWABLE SOURCES

Once estimated the consumption of neighborhood we are ready to design the supply of the energy required that, as suggested by the EPBD definition, should be produced on-site or nearby and from renewable sources.

To supply the energy required it has been decided to assess the photovoltaic and solar thermal to supply respectively electricity and DHW.

This choice has been suggested by the great potentialities that sun represents for Portugal, since it is one of the countries with the highest solar irradiation (fig. 39), being a crystalline silicon photovoltaic system at optimum angle able to generate annual average electricity of 1.494kWh per installed kWp compared to the 936kWh/kWp in Germany (EPIA 2012).

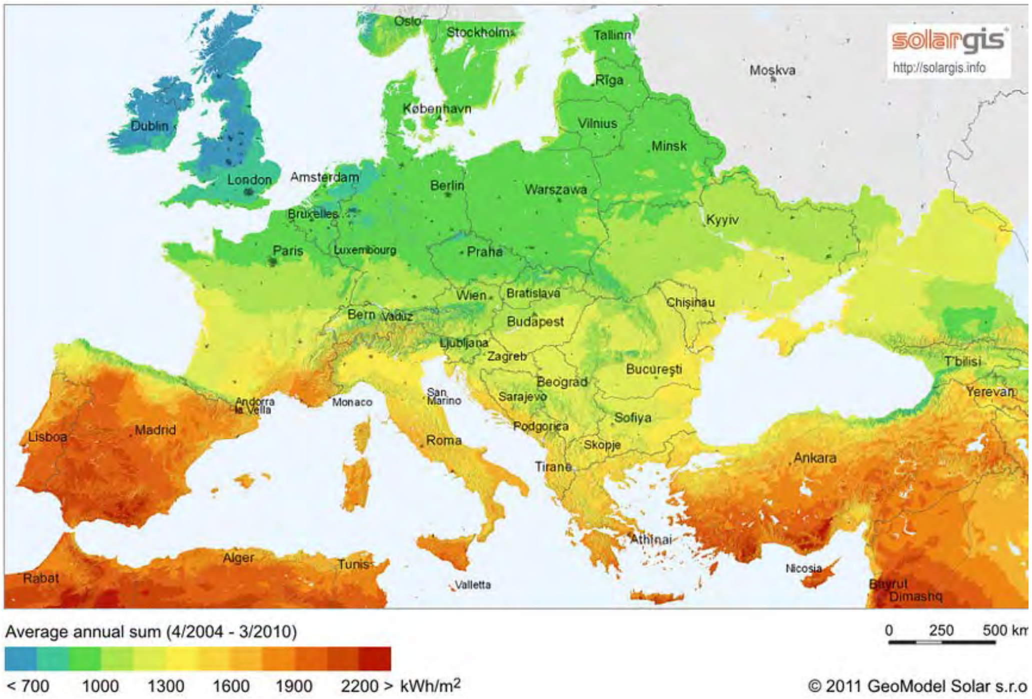

Figure 39: Map of the annual direct normal solar irradiation (Solargis 2011)

Despite this lower irradiation Germany is the leader producer of electricity from solar energy with a capacity of 24.678 MW at the end of 2011 compared to the 183 MW in Portugal (EPIA 2012), therefore in order to exploit the great potentialities of the Portuguese location a greater investment on solar energy is required.

4.4.1 SUPPLYING ELECTRICITY: PHOTOVOLTAIC

4.4.1.1 Sizing methodology

To size the photovoltaic system has been resorted the methodology suggested by Franchini (2012) based on the concept of equivalent hours (h_{eq}), which is the number of hours that the system works at the design conditions.

This concept is crucial in the photovoltaic because the peak power capacity (Pel,p) of the system is valid only for the project condition with solar irradiance of 1000W/m^2, condition that is verified only for few hours a year. It is therefore indispensable to know the equivalent number of hours a year that correspond to that ideal condition in order to be able to use the following equation:

$$E_{el} = h_{eq} * P_{el,p}$$

Since the $P_{el,p}$ of the system is referred to the irradiance of 1000W/m^2,which correspond to 1kW/m^2, knowing the daily irradiation in kWh/m^2 correspond to know the daily equivalent hours. Once know the equivalent hours it is enough to multiply them for the $P_{el,p}$ of the system to obtain the year energy production.

The information about solar irradiation is freely available in the web site http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php for different locations and orientations.

Knowing therefore the annual average number of equivalent hours a day is possible to obtain easily the annual production:

$$E_{el} = h_{eq} * P_{el,p} * 365 * R$$

With R=0,8 reductive factor to take into account that this methodology tends to overestimate the energy produced.

The limit of this equation is that it does not take into account that the efficiency of the cell is influenced by temperature conditions. In fact the nominal efficiency of the solar cell is given for the temperature of the cell of 25°C, but it is verified a reduction of efficiency due to higher cell temperatures and increasing of efficiency when the cell temperature is lower than 25°C.

It is possible therefore to proceed with a more accurate estimation of electricity produced estimating the monthly energy production, accounting the effect of the temperature through the correction factor TCF_i[15].

The equation to calculate the energy production becomes:

$$E_{el} = \sum_{i=1}^{12} h_{eq} * P_{el,p} * N_i * R * TCF_i$$

With N_i that is the number of days of the month and i the correspondent month.

To dimension the photovoltaic system therefore will be followed this second methodology, in order to take into account the variation of efficiency due to the different monthly conditions.

4.4.1.2 **PHOTOVOLTAIC IN MIRA SINTRA**

Before sizing the system, it is necessary to choose the model to be installed, since are the specifications of the system chosen that, together with the climatic conditions of the area studied, determines the quantity of energy produced.

Since the market of photovoltaic is really wide and it is difficult to take the proper choice, the choice of the model installed has been done entrusting to the suggestion of technicians, or energy enterprise that install photovoltaic.

Between the different information in terms of model and price[16] obtained from the enterprise contacted, it has been chosen the one that seems to offer a better balance between quality and price.

It has been chosen a panel Fluetcnick FTS-220P with a peak power of 240Wp. The solution has been suggested by the Portuguese enterprise Selfenergy, which already installed photovoltaic panels in the pilot project in Mira Sintra, and that informed AMES that the current price of the system installed is 2241€/KW_P including inverter and installation .

Table 23: Technical data and cost of the photovoltaic system chosen.

Model	Price (€/kWp)	Wp	NOCT (°C)	Ct	efficiency %	A (m^2)
Fluitecnik FTS-240P	2241	240	46	-0,0045	14,75%	1,63

The system has been dimensioned considering a south orientation with the inclination of 25°, which is the inclination of the roof of the building typology A.

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[15] Equation to calculate it in annex 7

[16] The list of the models and prices proposed are in the annex 6

Considering this orientation and that the neighborhood is in the municipality of Sintra, has been obtained the values of the daily average irradiation for each month (table 24) through the website http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php (JRC 2013).

Table 24: Daily average irradiation on a south facing surface with an inclination of 25° (JRC 2013)

	Jan	Feb	Mar	Ap	Mar	Ju	Jul	Aug	Sep	Oct	Nov	Dec
$H_m(25°)$ $(kWh/(m^2day))$	3,3	4,32	5,57	6,33	6,76	7,21	7,32	7,14	6,41	4,95	3,83	3,11

These values correspond to the daily equivalent hours in each month. Considering these equivalent hours, and with the proper correction due to the variation of the cell temperature compared to NOCT=25°, the power of the photovoltaic system has been calculated as 2,7MW$_p$ to produce 4173MWh[17] and thus covering the total electricity request of 4.101,6MWh.

Considering the dimension of the system chosen it would be necessary a surface of 18.337,5m^2. This surface in not available on the roofs of the typology A with orientation south, therefore it is necessary to find an alternative position.

This surface could be distributed in part on the roof of the typology A and in part on the flat roof of the equipment of the neighborhood, or alternatively, in the ample space undeveloped available in the east side of the neighborhood.

The result obtained shows an annual production of 1545 kWh/kW$_p$ that is higher than the value of 1494 kWh/kW$_p$ suggested by the study of the EPIA (2012) as average value for Portugal. This difference is higher than the numbers suggest, since the EPIA study is for the optimal angle, while in our case study the angle assessed is 25° and the optimal angle would be 34° (JRC 2013).

After calculating the quantity of panels needed to produce the energy required has been assessed the feasibility of the investment[18]. For this purpose it has been considered a discount rate of 5 % and a yearly O&M cost of 1% of the investment cost (IEA 2010).

Furthermore, since the photovoltaic system suffers of a linear degradation of efficiency, and the producer guarantees an efficiency of 80% after 20 years, it has been considered a 1% yearly reduction of the energy produced. This reduction has been accounted in the calculation of the payback as a yearly reduction of 1% of the annual savings. This maximum reduction of 1% a year in efficiency has been also confirmed by a study conducted by Jordan & Kurtz (2012).

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[17] Detailed calculation of the photovoltaic in annex 7

[18] Detailed calculation of the feasibility in annex 8

Therefore, with the current market price of 2241€/kW$_p$, to an initial investment of 6.050.700€ correspond a NPV of 2.729.581 considering 25 years the life of the system. The payback of the investment is of 12-13 years.

Table 25: Photovoltaic economy of scale

Photovoltaic EU market price (EPIA 2012)				
Power installed (kWp)	0-3	100	500	2.500
Price (€/kWp)	1.700-2.300	1.400-1.900	1.250-1.800	1.200-1.700
Price reduction (%)	0%	17%-18%	22%-26%	26%-29%

With the economy of scale observed by EPIA (2012), in average 27,5% for a system of 2,7MWp compared to the normal market price, the investment reduces to 4.386.758€ with a NPV at the end of 25 years of 3.775.256€. The payback is reduced to 8-9 years.

Despite the reduction due to the economy of scale, the investment has interesting payback both with and without benefitting of the discount due to scale. In both cases in fact the ratio between life of the system and payback is equal or higher than 2, so the investment guarantees profits for at least half of the life of the system. However thanks to the economy of scale the NPV increase of 38%, with increased earnings for 1.045.675€.

With its production of 4173,1MWh/a of electricity the implementation of photovoltaic implies a reduction of 1948,8 tons of CO2 every year.

4.4.2 SUPPLYING DOMESTIC HOT WATER: SOLAR THERMAL

4.4.2.1 Sizing methodology

To size the solar thermal has been followed the methodology suggested by Franchini (2012) that calculates the area of collector (A_c) needed to provide the daily DHW as:

$$A_c = \frac{Q_{HW}}{Energy\ flow\ absorbed} = \frac{Q_{HW}}{\eta_m * H_m} \quad \text{and} \quad Q_{HW} = V_{DHW} * C_w * \Delta T$$

With η_m that is the average efficiency of the collector, H_m the average daily solar irradiation, and Q_{HW} the energy required to heat the volume of hot water required.

As for the photovoltaic, the main problem is to obtain the η_m. The efficiency of the collector is in fact a function of the exterior temperature.

$$\eta_m = \eta_o - a_1 * X - a_2 * G * X^2 \quad ,$$

being $X = \frac{(tm-ta)}{G}$ dependent on the exterior temperature and

being η_o, a_1 and a_2 values supplied by the producer for the specific collector chosen.

With this methodology therefore, chosen the collector model to install and knowing the average daily irradiation (H_m) and the exterior daily average exterior temperature for each month, it is possible to calculate the surface that would be needed each month to produce the total amount of hot water needed.

The problem is that to supply 100% of the hot water the surface needed in winter would be much higher than is summer since the solar irradiation is lower. There are two reasons that suggest not sizing the system to cover 100% of DHW need. Firstly sizing the system for the worst condition would be too expensive and secondly it would incur in the risk of stagnation, which would cause the arrest of the system of the system, due to overheating of the water in the collectors in summer caused by the oversizing. This is why In general the solar fraction suggested is around 55-60% (Kingspan 2013).

It is necessary therefore to choose a surface area that guarantees a correct solar fraction, or in other words the percentage of DHW covered with solar thermal.

4.4.2.2 **Solar thermal in Mira Sintra**

Similarly to what has been done for the photovoltaic system, to choose the models of solar thermal it has been consulted some technicians that work in this sector.

From the information obtained it has been decided to assess two different technologies, a flat collector and a vacuum tube collector. This is due to the fact that, despite a higher purchase price, the vacuum tube presents lower values of a_1 and a_2 and therefore keeps a higher efficiency also when it is not working in the ideal condition.

Between the models proposed[19] it has been chosen the flat collector Valliant auto plus, suggested by the engineer Antonio Tucci of the enterprise TECHNE ENERGHEIA with a price of 900€/m^2.

For the vacuum tube solution it has been chosen the solution Thermomax of Kingspan suggested by the technician Giannino Basso, Italian consultant for the enterprise Kingspan. In the category Thermomax it has been chosen the model DF100-30 available in Portugal with a price of 1719€/m^2 (CYPE 2013).

Both the prices for flat and vacuum tube collector include installation and tank needed to storage the DHW produced. They are both VAT excluded.

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[19] The list of the models and prices proposed are in annex 6

The flat collector Valliant auto plus has been chosen to be a good balance between quality and price, while the Thermomax to be one of the best quality product available in the market being the first to receive the European quality mark for solar collectors – The Solar Keymar (REC 2013), and being awarded in the International Forum Design award for excellence in product design in 2005 (RatedEnergy 2013).

4.4.2.2.1 Flat solar collector

The solar thermal collector has been dimensioned[20] considering 122.597l the daily consumption for all the buildings typology A. This request has been calculated considering the consumption of 40l/(inh*day) at a temperature of 60° and with an average supply temperature of the aqueduct water of 15°C (RCCTE 2006). The solar collectors are considered south oriented and with an angle of 25° equal to the inclination of the pitched roof.

Table 26: Technical data and cost of the flat solar collector chosen.

Model	Price (€/m^2)	η_o	a_1(W/m^2K)	a_2(W/m^2K)	Ac (m^2)	A_{tot} (m^2)
Valliant auto plus	900	0,832	3,297	0,017	2,33	2,5

From the results of the sizing can be observed that in December, the month with lower irradiation, the Ac required to satisfy the DHW request would be 5746m^2 against the 1400 m^2 for July. This high difference is due in part to the difference of irradiation, 3,11kWh/m^2 in December compared to 7,32kWh/m^2 in July and to the reduction of the efficiency η_m that is 64% in August while it's only 36% in December.

Choosing 1400 m^2, the minimum surface required to satisfy the need in July, the hot water produced cover a solar fraction of 67%. It is interesting to notice how in Portugal the solar fraction suggested of 55-60% can be easily exceeded without risk of stagnation, since all the hot water produced is consumed every month. This is probably a consequence of the fact that, unlike the northern countries, the winter is not really rigid and so the efficiency decrease of the collector is lower than in the other countries.

Installing 1400m^2 of flat collectors with the price of 900€/m^2 the investment is of 1.260.000€ and thanks to the solar fraction covered the energy saved is the 67% of what consumed by the gas boilers currently used in the residential buildings. Being the consumption for all the building units A 4809,7MWh/a (table 27) and being the price of gas in Portugal 0,056€/kWh without VAT (EEP 2013) the annual savings correspond to 179.318€.

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[20] Detailed sizing of the solar collector in annex 7

Table 27: Current natural gas consumption to supply DHW

Building unit	Position	Number units	Total floor area (m^2)	DHW (kWh/m^2a)	Total DHW(MWh/a)
A	Edge unit	94	59.525,5	47,81	4809,7
	Central Unit	66	41.794,5	46,97	

Considering a yearly O&M cost of 1% of the initial investment, the NPV considering a life of 25 years is 1.089.722€ and the time payback 9-10 years[21].

The 1400m^2 of capture surface would cover 1502 m^2. This surface is available on the roof of the building typology A south facing, therefore solar thermal can be entirely allocated on the roof of the buildings A. This is important since, unlikely of electricity, the efficiency of the distribution of the heat is significantly influenced by the distance travelled between production and consumption.

Table 28: Solar thermal economy of scale

Solar thermal EU market price (Schnauss 2008)				
Surface (m^2)	10-20	20-30	30-50	>50
Price (€/m^2)	650-700	530-580	450-530	350-480
Economy of scale (price reduction)	0%	17%-18%	24%-31%	31%-46%

The economy of scale observed by Schnauss (2008) therefore suggests an average reduction of 38,5% compared to the normal market price being the surface higher than 50m^2. Considering this reduction the investment reduces to 774.900€ with a NPV at the end of 25 years of 1.643.192€. The payback is reduced to 5-6 years.

The investment is interesting both with normal and with discounted price, considering that in both cases for half of the life of the system the savings are earnings. Thanks to the discounted price however the total profit of the investment in significantly higher, becoming higher than the initial investment. Due to the economy of scale for the 75% of their life the solar collector will generate earnings.

The flat solar collector covering the 67% of the DHW request determines annual savings of 3222,5MWh. Considering that for each kWh of natural gas consumed are emitted 0,184 kgCO_2 (CARBON TRUST 2013) the environment benefits from a reduction of 592,9 tons of CO_2 released.

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[21] Detailed calculation of the feasibility in the annex 8

4.4.2.2.2 Vacuum tube collector

Similarly has been proceeded with the dimensioning[22] of the Thermomax DF100-30 with the following characteristics:

Table 29: Technical data and cost of the vacuum solar tube collector chosen.

Model	Price (€/m^2)	η_o	a_1(W/m^2K)	a_2(W/m^2K)	Ac (m^2)	A_{tot} (m^2)
Thermomax DF100-20	1719	0,832	1,14	0,0144	3,23	4,25

From the sizing can be noticed how the decrease of efficiency in different months is lower than for the flat collector being $\eta_{m\ =}$75% August and 63% in December. Due to this better behavior with a capture surface of 1150m^2 the solar fraction covered is then 71%.

The feasibility study[23] however shows how, at least for the Portuguese irradiation condition, the investment is not financially interesting. In fact considering the price of 1719€/m^2 the payback is 17-18 years.

The economy of scale underlined by Schnauss (2008) significantly improves the feasibility of the investment. Reducing the price to 1057€ the NPV becomes 1.299.518€ and the payback 8-9 years. Thanks to the economy of scale also the solution of the vacuum tube become an interesting investment.

Comparing the result of the flat collector and vacuum tube it has been chosen the flat collector as solution to be implemented. In fact, beyond a faster payback and a higher NPV, the flat collector do not need of a higher surface to be installed. In fact although the capture surface of the collector is significantly higher for the flat collector, being 1400m^2 compared to 1150m^2 of the vacuum tube, the total surface needed is respectively 1502m^2 for the flat collector and 1513m^2 and therefore with the same surface covered the vacuum tube increases the production of hot water only of 4%, from 67% to 71% of solar factor.

4.5 DISCUSSION OF THE RESULTS OF THE CASE STUDY

The approach proposed for the Mira Sintra case study has the limitation of being affected by the many suppositions that has been taken, since much information about the neighborhood was not available. For example all the thermal characteristics of the buildings have been supposed since the only information found is that the buildings are in precast concrete. To this has to be added the approximation of the results of the calculations due to the fact that the simulations with

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[22] Detailed sizing of the solar collector in annex 7

[23] Detailed calculation of the feasibility in annex 8

Design Builder have been run considering the climate data of Coimbra, since the data for Sintra are not freely available in the program.

Despite these limitations, the work shows a possible approach of intervention at urban scale, and how proceeding to a typification of the building stock is possible to make easier the calculation and obtain an estimation of the consumption of the neighborhood without the need of modeling all the single buildings.

In the case the refurbishment of the neighborhood of Mira Sintra will be materialized, it could be followed the approach suggested after a more detailed analysis of the construction solutions, to obtain more reliable estimation of the thermal properties of the building envelope, and could be bought the program Sol Term to simulate the buildings with the correct climate condition of Sintra.

Despite their approximation, the results allow interesting considerations about the intervention at neighborhood scale concerning both performance and costs.

Table 30: Recapitulation of the feasibility study

Solution	Payback (years)			NPV (€)		
	With normal price	With discount price	Reduction (%)	With normal price	With discount price	Increase (%)
ETIC 6 cm	12-13	8-9	31-33%	3.294.396	4.238.552	28,7%
Double glazing	25-26	15-16	38,5-40%	167.320	697.493	316,9%
Roof insulation	1-2	1-2	0%	1.494.782	1.547.831	3,5%
Tot refurbishment	11-12	8-9	25-27%	5.086.507	6.613.886	30%
Photovoltaic	12-13	8-9	31-33%	2.729.581	3.775.256	38,3%
Flat collector	9-10	5-6	40-44%	1.089.722	1.643.192	50,8%
Vacuum Tube	17-18	8-9	50-53%	431.164	1.299.518	201,4%

Table 30 underlines how, thanks to the economy of scale, significant reductions of the time payback have been verified for all the solutions proposed. Benefitting of the discount price all solutions proposed have interesting payback and become feasible.

The economy of scale is particularly interesting to enable those solutions that due to high investment cost, as double glazing windows and vacuum tubes solar collectors are not interesting investments at single building scale. The benefit of the scale seems even clearer when considering the investment return, the NPV in fact in many cases duplicate comparing the urban and building scales.

Moreover it is important to observe how the results obtained are influenced by the assumptions taken. They are therefore firstly referred to the fact that in the analysis two opposite scenarios have been compared. The feasibility has been calculated in fact comparing the scenario of the energetic refurbishment proposed and a scenario without any intervention.

Secondly they are influenced by the fact that prices have been considered constant. It has been in fact considered that the price of energy, electricity and natural gas, will be constant in future. There are however many studies that suggest significant future increase of energy prices (e.g. EC 2011b; EPIA 2011; IEA 2010).

Choosing to compare the scenario of refurbishment proposed with the scenario of no intervention has been chosen the most disadvantageous scenario. With this choice in fact all the initial investment to implement the solution proposed is included as negative cash flow to calculate the payback and NPV. Since the buildings have been built in 1965 in fact it would have been alternatively possible to compare the scenario of the energetic refurbishment proposed, with the scenario of refurbishment to simply guarantee the correct functioning of the building.

In addition it has been considered that the O&M cost happens only in the scenario of the energetic refurbishment, and no maintenance cost is considered in the scenario without refurbishment. It has been therefore considered that currently there is no maintenance although it would be necessary to keep the quality of the buildings.

These choices have been taken because it has been assumed that, despite it would be recommended, the custom is not to do regular maintenance to the buildings. However, being aware that this maintenance is necessary to guarantee the specifications of the building materials, this cost has been included for the solutions proposed. It is in fact necessary to change the mentality of the people, changing the habit from a reactive to a preventive or even proactive intervention.

Secondly also considering the constant price of energies it has been chosen the more disadvantageous hypothesis. The payback and NPV has been considered in fact keeping constant the price of electricity 0,165€/kWh and natural gas 0,056€/kWh. The inclusion of the expected increases in energy price would have improved the feasibility of the solutions reducing the time payback and increasing the NPV.

Considering for example the EPIA (2011) scenario that suggests a compound annual growth rate (CAGR) of 3,5% till 2020 and then of 2% till 2050 for electricity price, the result of the feasibility study would be significantly different. Considering for example the feasibility of photovoltaic, with the discounted due to the economy of scale, the payback would reduce from 8-9 years to 7-8 years and, even more significant, the NPV would increase of 52% from 3.775.256€ to 5.759.507€.

These considerations underline how results obtained from the feasibility study are conservative, and there are therefore good reasons to think that the NPV in the reality could be higher.

Finally it is interesting to quantify the result for a single building, to see if the results obtained turn the building in NZEB. Considering building unit A in the edge position, its consumptions after refurbishment are 40,17kWh/m^{2}a of electricity and 47,8kWh/m^2 of natural gas (table 31). These final energy consumptions correspond respectively to 135,4kWh/m^2 of electricity and 47,8kWh/m^2 of natural gas of primary energy considering the conversion factor of the RCCTE.

Table 31: Building consumption after refurbishment

Building	Position	Heat (kWh/m^{2}a)	Cool (kWh/m^{2}a)	Light and appliances (kWh/m^{2}a)	DHW (kWh/m^{2}a)
A	Edge	24,31	5,76	10,1	47,8

To valuate if the building is a NZEB it is now necessary to subtract the energy produced on site to obtain the net energy need. In fact as already noticed from the REHVA definition of NZEB (Kurnitski et al. 2011a), the net energy need is calculated as delivered energy minus exported energy, but the production on site from renewables is not accounted as delivered energy.

Due to the fact that 100% of electricity is supplied by photovoltaic and that 67% of DHW is produced from solar thermal, with the flat solar collector, the primary energy accounted to the building would be the 33% of the DHW consumption. The consumption of the building would be therefore 15,77kWh/(m^{2}a) of primary energy.

Since there are not yet official values for nearly zero energy, it has been considered the value of 40kWh/ m^2 of primary energy set by Kurnitski et al. (2011b). Considering this value as reference for NZEB the building typology A after the intervention with its net energy need of 15,77KWh/m^2 can be considered a NZEB.

The results obtained for the case study show intervening at urban scale nearly zero energy can be achieved with a time payback lower than 10 years.

5 CONCLUSIONS

The objective of the thesis is to identify what building and urban design strategies must be followed to assure a good balance between costs and nearly zero energy and carbon level.

Within the many challenges that the urban scale suggests, as the availability of alternative strategies, the homogenization of the consumption pattern, the great influence of urban morphology, factor 2, and the opportunity to include transport consumption in the boundaries of nearly zero energy it has been decided to focus the work in the case study to the benefits that economy of scale brings to the feasibility of the investment.

The methodology used, due to the increased complexity of the urban scale, involves the need of typifying the building stock in few typologies compared by similar consumptions. The application of this approach to the case study has shown how, in the case of Mira Sintra, it has been possible to typify the whole neighborhood with only 3 building models, without incurring in too high losses in accuracy. The interpretation of the results (section 4.2.2) show in fact for example how the choice of representing the typology A with the building unit A1 rotated 42° guarantee a maximum variance of 5,4% compared to lowest and highest consumption of this typology.

The results obtained from the case study show that thanks of the economy of scale the investment needed to implement all the solutions proposed, both passive and active with the only exception of the substitution of the windows, is recovered in less than 10 years due to the annual savings (section 4.4). Also the time payback achieved for the windows start to be economically interesting, being the investment recovered in half of the windows' life.

The refurbishment proposed with a 6cm ETICS, PVC windows with double glazing and thermal insulation of the roof cause outstanding reduction of the consumptions for heating and cooling, which for the edge unity of the typology A is of 63%, from 82kWh/m2a before to 30kWh/m2a after the rehabilitation (section 4.2.3.4). The refurbishment furthermore determines a reduction of 2077,9 tons of CO_2 a year.

The combination, additionally to the passive solutions, of photovoltaic and solar thermal systems which cover respectively the 100% and the 67% of electricity and DHW needs, allows to reduce the net energy demand of the typology A to 15,8 kWh/m2a of primary energy, thus satisfying the nearly zero energy standard (section 4.4).

The combination of passive and active solutions determine a reduction of 4648,9 tons of CO_2 a year. The CO_2 emission of the neighborhood after the implementation of passive and active solutions is of 292 tons of CO_2 a year, with a reduction of 94% compared to the current emissions.

The implementation of nearly zero energy to urban has shown therefore that thanks to the economy of scale the achieving of nearly zero energy is feasible, and can be obtained with time payback lower than 10 years.

These results underline how NZEUA could be a challenge to reach cost optimality, in particular considering that the results obtained are consequence only to the advantages of the reduction of purchase price due to economy of scale.

Even better results could be obtained introducing the other variables that at urban scale suggest a better performance. Including in the analysis of the case study possible alternative strategies to supply energy, as for example CHP, and the homogenization of the consumption patterns with the reduced size of the power of the supply system could in fact improve the performance with a better rationalization of energy production, thus further reducing the cost of implementation of the supply system and reducing the time to recover the investment.

In addition it is interesting to observe how the approach to urban scale offers several approaches to nearly zero energy. The choice depends on the peculiarities of the case study. For example while in the case of refurbishment morphology cannot be determinant in controlling consumptions, since there is a little chance to modify the structure of the neighborhood once built, it can be determinant from the planning stage for a new development. The approach to urban scale therefore suggests a great flexibility in achieving nearly zero energy, and so the choice of the best strategy to apply has to be studied case by case.

Moreover the urban scale offers the advantage not to limit the intervention to buildings consumptions. At urban scale in fact public consumptions, as public lightings can be included and urban scale offer the opportunity to widen the nearly zero energy boundaries to transport, which is responsible for 31% of total EU consumption, and thus greatly affect the total consumption within Europe.

Finally the tight correlation between morphology and building and transport consumption, involving the urban planners and designers in the process to nearly zero energy, could turn NZEUA to be a linking platform between energy and urban design, and thus not being limited to the energy sphere, but becoming an instrument to achieve sustainable development, thus increasing the livability of the cities.

The way to NZEUA nevertheless is anything but unobstructed. There are many complications that the urban scale introduces since urban environment is much more complex than the building ambit.

The great variability of scales is an issue anything but easy to deal with. Determine which are the proper dimensions to apply nearly zero energy is not an easy question to answer. As point out by Koch (2009) the increasing number of buildings considered in the energy balance would raise complexity in calculation. However the increased scale clustering more buildings introduces significant advantages, inter alias allowing alternative strategies of supply system and reducing significantly the consumptions.

Different scales could trigger different advantages, so the discussion should be focused not to which is the proper dimension but which could be proper dimensions to benefit from the advantages of increasing the scale but without compromising the complexity in calculations. Different approaches to nearly zero energy could be suitable to different scales.

Urban scale would also determine a notable increased number of actors and stakeholders involved. This could be another limiting factor. The coordination between different stakeholders could slow down the process for the presence of conflicting interests.

The increased scale would also increase the total initial investment. Even though there are many evidences that with the new scale there would be a reduction of unity costs compared to the building level, the bulky acquisition would require a notable total investment. To overtake this complication, since it’s not easy to find a single investor with economic power to support this expense, alternative and proper loan strategies should be found.

Further studies should focus on the detail analysis of the implications of the parameter not assessed in this works to a case study. The quantification of the results due to alternative strategies, homogenization of consumptions, and control urban form is necessary to obtain a more detailed quantification of the advantages of the new scale.

Moreover, due to the great effect that transport plays in EU, should be discussed how transport could be included in the boundaries of nearly zero energy, which are the complications that this inclusion imply, and which could be the targets of transport consumptions.

Therefore considering the tight binding targets set by EU for 2020 and 2050 and that the urban scale, beyond contributing to reduce GHG emission, could be a challenge to reach cost optimal level, this work suggests a further discussion of the potentialities and limitations of NZEUA and eventually put it into the EU agenda.

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ANNEX 1: CHARACTERIZATION OF THE NEIGHBORHOOD

In this annex it will be presented the tables showing the values of the urban characterization of the neighborhood. The information about number and dimension of the buildings as gross floor area and lot coverage has been extrapolated from Google maps and by measurements on the spot, while the net floor area has been estimated considering the drawings in the annex 3.

Table 32: Characterization of the typologies

Values for the building units					
Typology	A		B		C
Sub Classes	A1	A2	B1	B2	C
Lot coverage (m^2)	153,5	192,9	518,6	588,4	149,6
Net floor area (m^2)	126,6	164,2	447,5	514,7	134,9
N floors	5	5	9	9	2
Gross floor area (m^2)	767,5	964,5	4667,4	5295,6	299,2
N of apartments each floor	2	2	4	4	0,5

Table 33: Characterization of the Neighborhood: residential dwelling

Values for the neighborhood: residential						
Sub classes	A1	A2	B1	B2	C	Tot
N of buildings unit	60	100	5	5	54	224
N apartments	600	1000	180	180	108	2068
Tot lot coverage (m^2)	9210,0	19290,0	2593,0	2942,0	8078,4	42113,4
Tot net floor area (m^2)	37995,0	82080,0	20136,2	23161,5	14564,9	177937,5
Tot gross floor area (m^2)	46050,0	96450,0	23337,0	26478,0	16156,8	208471,8

Table 34: Characterization of the neighborhood including local equipment

Values for the neighborhood including equipment			
	Residential	Local Equipment	Total
Lot coverage (m^2)	42135	17971	60106
Gross floor area (m^2)	208515	23708	232223

Table 35: Urban characterization of the neighborhood

Neighborhood Mira Sintra			
Land surface area (ha)	42ha		
Population (inh)	4677 (source: INE 2011)	Pop density (inh/ha)	111,36
Number of families	1800 (source: INE 2011)	Average family (inh/fam)	2,60
Number of apartments	2109 (source: INE 2011)	Empty apartments[24] (%)	14,65
Lot coverage (m^2)	60106	Lot coverage ratio	0,14
Open space area (m^2)	359.894	Open space ratio	0,86
Gross floor area (m^2)	232.223	Gross floor area ratio	0,55

ANNEX 2: CONSTRUCTION SOLUTIONS OF THE RESIDENTIAL BUILDINGS

In this annex it will be presented the assumptions that have been taken to simulate the residential building stock in Mira Sintra, and the characteristics of the refurbishment solution proposed.

CONSTRUCTION SOLUTIONS BEFORE REFURBISHMENT

Not knowing exactly the solution implemented in the buildings, it has been chosen in the library of Design Builder the solutions that seem reasonable, basing on the fact that the buildings are not insulated, in precast concrete (AMES 2007) with a thickness of the walls of 25 cm, and that the typology A and C have an not insulated unoccupied pitched roof while the typology B has a concrete not insulated flat roof.

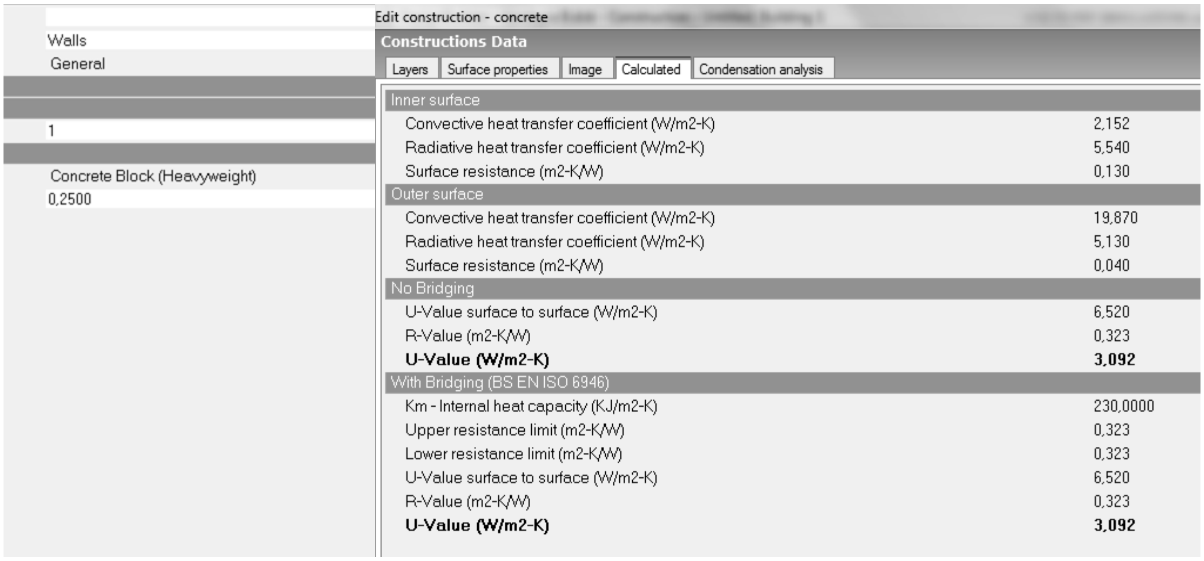
Here follows the materials used for the simulation with Design Builder.

EXTERNAL WALL

It has been chosen a 25cm Concrete Block Heavy-weight wall with the following characteristics:

---

[24] The percentage of empty apartments are calculated considering that the number of apartments available correspond to the maximum number of families that can be collocated in the area.



Walls
General
1
Concrete Block (Heavyweight)
0,2500

Edit construction - concrete

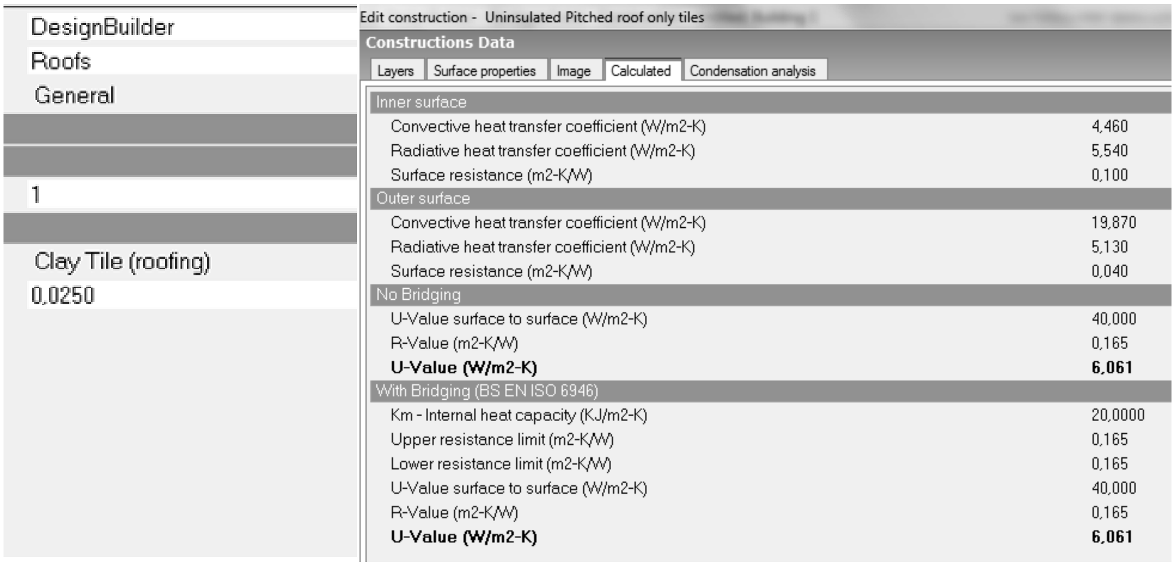
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2,152
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,040
No Bridging	
U-Value surface to surface (W/m2-K)	6,520
R-Value (m2-K/W)	0,323
U-Value (W/m2-K)	**3,092**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	230,0000
Upper resistance limit (m2-K/W)	0,323
Lower resistance limit (m2-K/W)	0,323
U-Value surface to surface (W/m2-K)	6,520
R-Value (m2-K/W)	0,323
U-Value (W/m2-K)	**3,092**

Figure 40: Not insulated external wall (source: Design Builder)

NOT INSULATED PITCHED ROOF

It has been chosen a not insulated medium weight pitched roof composed by 2,5cm of clay tile with the following characteristics:



DesignBuilder
Roofs
General
1
Clay Tile (roofing)
0,0250

Edit construction - Uninsulated Pitched roof only tiles

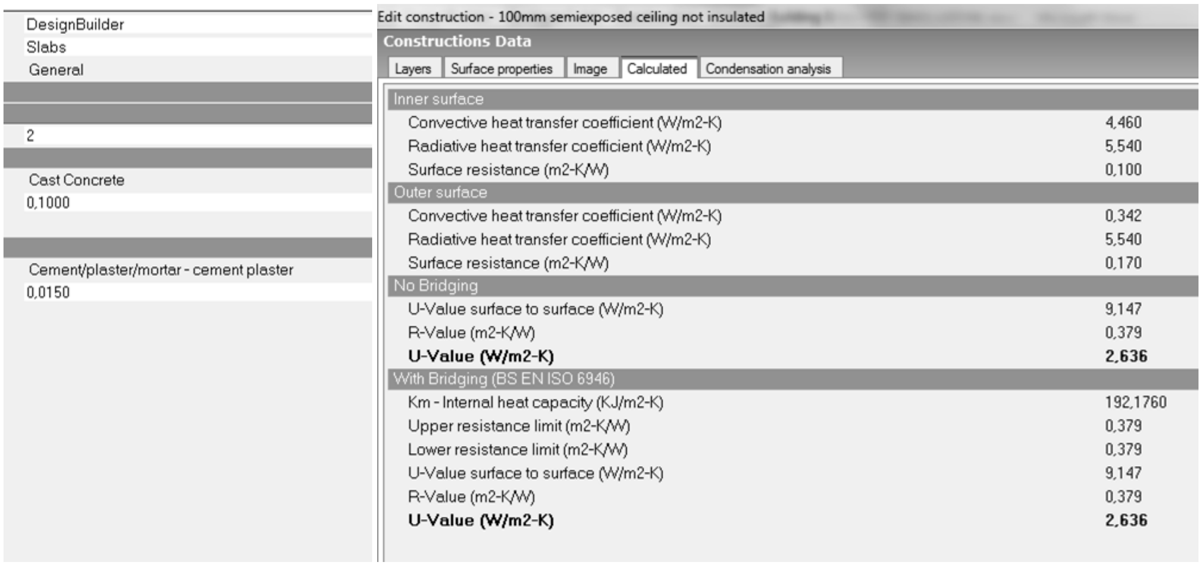
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,040
No Bridging	
U-Value surface to surface (W/m2-K)	40,000
R-Value (m2-K/W)	0,165
U-Value (W/m2-K)	**6,061**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	20,0000
Upper resistance limit (m2-K/W)	0,165
Lower resistance limit (m2-K/W)	0,165
U-Value surface to surface (W/m2-K)	40,000
R-Value (m2-K/W)	0,165
U-Value (W/m2-K)	**6,061**

Figure 41: Not insulated pitched roof (Source: Design Builder)

SEMIEXPOSED CEILING UNDER PITCHED ROOF

It has been chosen a 10 cm cast concrete slab finished with 1,5cm of plaster with the following characteristics:



DesignBuilder
Slabs
General
2
Cast Concrete
0,1000
Cement/plaster/mortar - cement plaster
0,0150

Edit construction - 100mm semiexposed ceiling not insulated

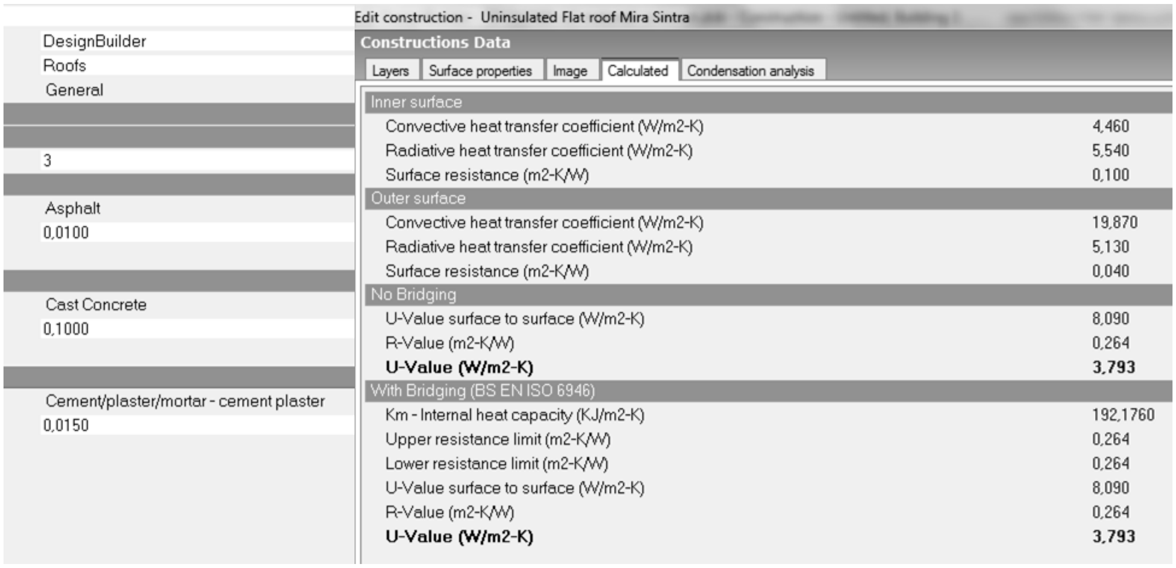
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	0,342
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,170
No Bridging	
U-Value surface to surface (W/m2-K)	9,147
R-Value (m2-K/W)	0,379
U-Value (W/m2-K)	**2,636**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	192,1760
Upper resistance limit (m2-K/W)	0,379
Lower resistance limit (m2-K/W)	0,379
U-Value surface to surface (W/m2-K)	9,147
R-Value (m2-K/W)	0,379
U-Value (W/m2-K)	**2,636**

Figure 42: Not insulated semi-exposed ceiling under pitched roof (source: Design Builder)

FLAT ROOF

It has been chosen a not insulated heavy-weight flat roof composed by 1,5 cm of plaster, 10 cm of cast concrete and 1cm of asphalt with the following characteristics:



DesignBuilder
Roofs
General
3
Asphalt
0,0100
Cast Concrete
0,1000
Cement/plaster/mortar - cement plaster
0,0150

Edit construction - Uninsulated Flat roof Mira Sintra

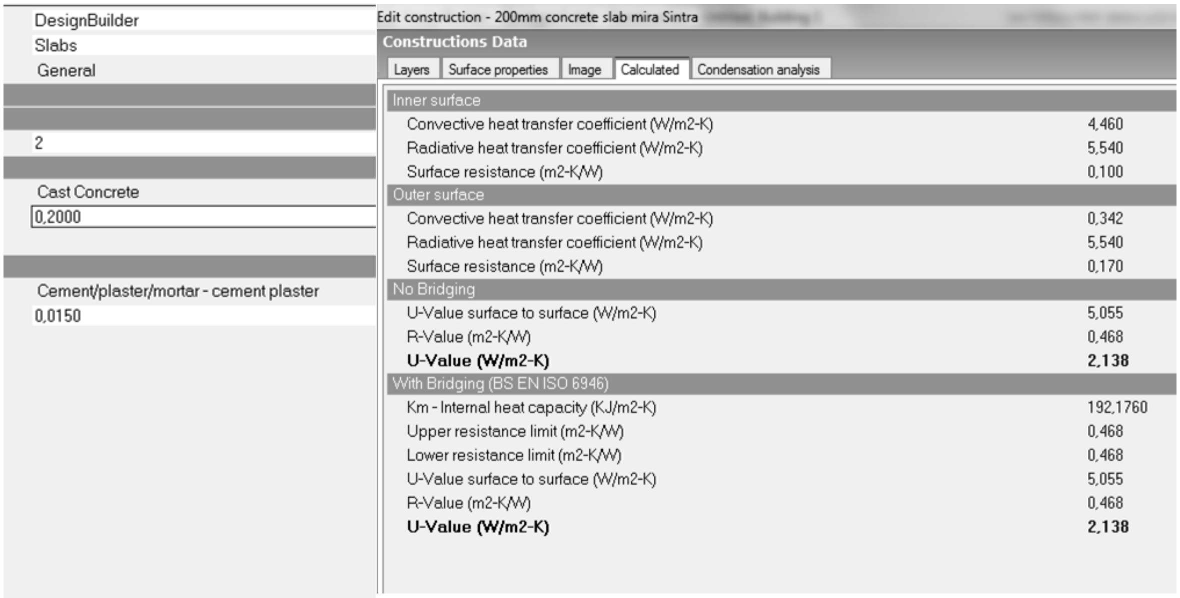
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,040
No Bridging	
U-Value surface to surface (W/m2-K)	8,090
R-Value (m2-K/W)	0,264
U-Value (W/m2-K)	**3,793**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	192,1760
Upper resistance limit (m2-K/W)	0,264
Lower resistance limit (m2-K/W)	0,264
U-Value surface to surface (W/m2-K)	8,090
R-Value (m2-K/W)	0,264
U-Value (W/m2-K)	**3,793**

Figure 43: Not insulated flat roof (Source: Design Builder)

FLOOR SLABS

For all the others floors slabs it has been chosen a 20cm cast concrete slab with the following characteristics:


DesignBuilder
Slabs
General
2
Cast Concrete
0,2000
Cement/plaster/mortar - cement plaster
0,0150

Edit construction - 200mm concrete slab mira Sintra

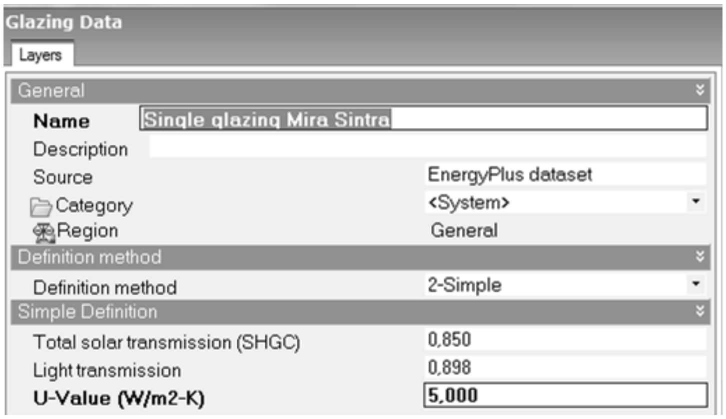
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	0,342
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,170
No Bridging	
U-Value surface to surface (W/m2-K)	5,055
R-Value (m2-K/W)	0,468
U-Value (W/m2-K)	**2,138**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	192,1760
Upper resistance limit (m2-K/W)	0,468
Lower resistance limit (m2-K/W)	0,468
U-Value surface to surface (W/m2-K)	5,055
R-Value (m2-K/W)	0,468
U-Value (W/m2-K)	**2,138**

Figure 44: Not insulated floor slabs (Source: Design Builder)

GLAZING

For the glazing it has been chosen a single glass with the following characteristics:


Glazing Data

General	
Name	Single glazing Mira Sintra
Description	
Source	EnergyPlus dataset
Category	<System>
Region	General
Definition method	
Definition method	2-Simple
Simple Definition	
Total solar transmission (SHGC)	0,850
Light transmission	0,898
U-Value (W/m2-K)	**5,000**

Figure 45: Single glazing (Source: Design Builder)

The value of 5W/m^{2}K is considered weighted up between glass and frame properties following the indication of ENEA (2013).

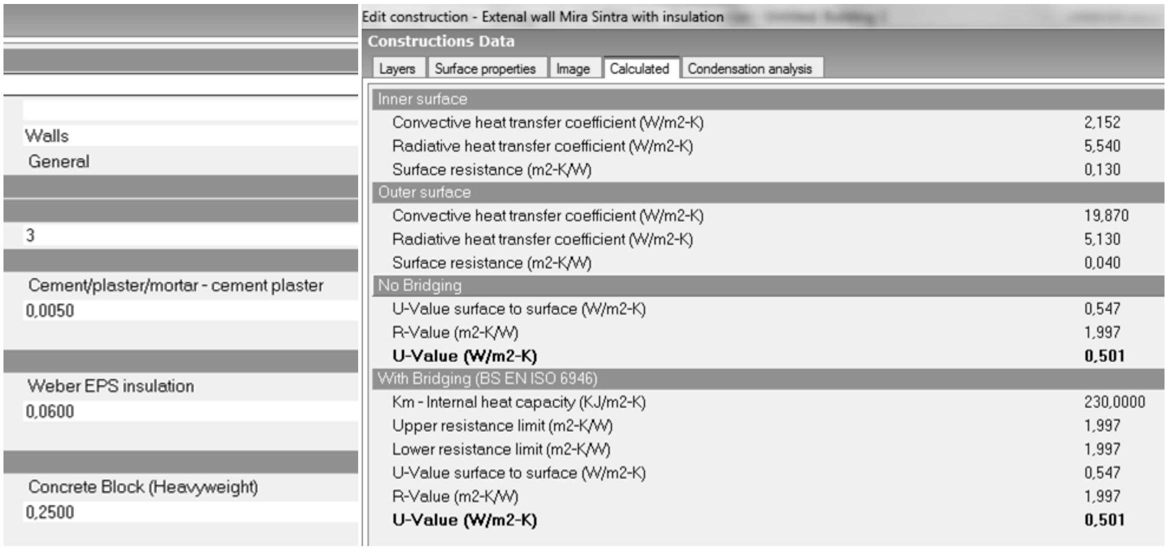
It has been considered an infiltration rate of 1,05ac/hour through the envelope, as calculated through the indication of the RCCTE.

CONSTRUCTION SOLUTIONS AFTER REFURBISHMENT

EXTERNAL WALLS WITH INSULATION

To the 25cm Concrete Block Heavy-weight wall it has been added an ETICS with EPS rigid panels with a width of 6 cm.

The characteristics of the walls with the new insulation are the followings:



Edit construction - Extenal wall Mira Sintra with insulation

Constructions Data

Walls

General

3

Cement/plaster/mortar - cement plaster

0,0050

Weber EPS insulation

0,0600

Concrete Block (Heavyweight)

0,2500

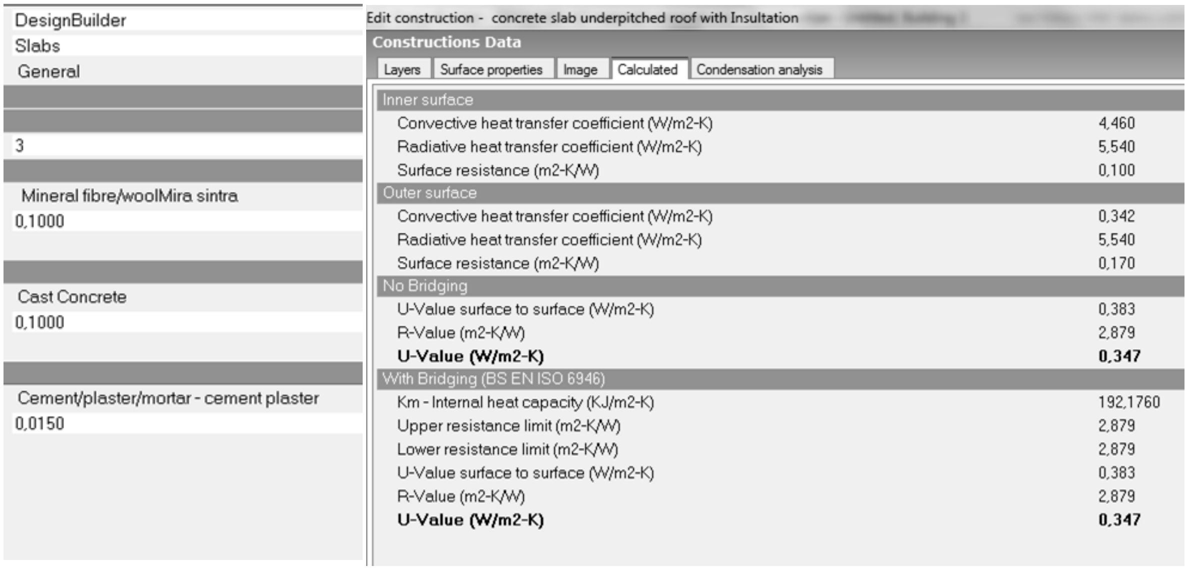
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2,152
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,040
No Bridging	
U-Value surface to surface (W/m2-K)	0,547
R-Value (m2-K/W)	1,997
U-Value (W/m2-K)	**0,501**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	230,0000
Upper resistance limit (m2-K/W)	1,997
Lower resistance limit (m2-K/W)	1,997
U-Value surface to surface (W/m2-K)	0,547
R-Value (m2-K/W)	1,997
U-Value (W/m2-K)	**0,501**

Figure 46: Insulated external wall (Source: Design Builder)

UNOCCUPIED PITCHED ROOF (INSULATION ABOVE THE LAST FLOOR CEILING)

In the typology A and C, in presence of the not insulated pitched roof, the solution chosen is to put thermal insulation above the ceiling of the last floor.

The ceiling with 10 cm of mineral wool of insulation has the following characteristics:



DesignBuilder
Slabs
General
3
Mineral fibre/woolMira sintra
0,1000
Cast Concrete
0,1000
Cement/plaster/mortar - cement plaster
0,0150

Edit construction - concrete slab underpitched roof with Insultation

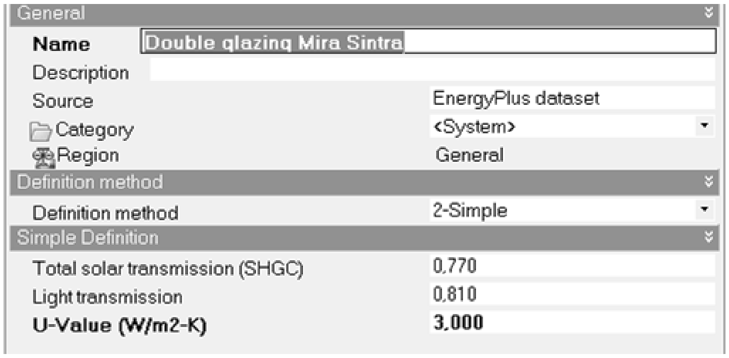
Constructions Data

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	0,342
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,170
No Bridging	
U-Value surface to surface (W/m2-K)	0,383
R-Value (m2-K/W)	2,879
U-Value (W/m2-K)	**0,347**
With Bridging (BS EN ISO 6946)	
Km - Internal heat capacity (KJ/m2-K)	192,1760
Upper resistance limit (m2-K/W)	2,879
Lower resistance limit (m2-K/W)	2,879
U-Value surface to surface (W/m2-K)	0,383
R-Value (m2-K/W)	2,879
U-Value (W/m2-K)	**0,347**

Figure 47: Insulated semi-exposed ceiling (Source: Design Builder)

DOUBLE GLAZING WITH PVC FRAME

It has been chosen a glass composed by two layers of 4mm of glass divided by 10mm of air with the following characteristics:



General	
Name	Double glazing Mira Sintra
Description	
Source	EnergyPlus dataset
Category	<System>
Region	General
Definition method	
Definition method	2-Simple
Simple Definition	
Total solar transmission (SHGC)	0,770
Light transmission	0,810
U-Value (W/m2-K)	**3,000**

Figure 48: Double glazing (Source: Design Builder)

For the PVC frame was chosen a frame with a width of 7,4cm and an U value of 1,3W/(m^2K) (CYPE 2013).

REFURBISHMENT PROPOSED. TECHNICAL DATA AND COSTS

Table 36: 6cm ETICS. Description and costs (CYPE 2013)

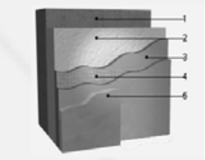
NAS031	**m²**	**Sistema ETICS weber.therm "WEBER CEMARKSA" de isolamento exterior de fachadas com revestimento mineral.**		
Unitário	Ud	Descrição	Importância Edificio singolo	Importância todo bairro
mt28maw020	kg	Argamassa base weber.therm Base "WEBER CEMARKSA", para fixação e regularização de placas de isolamento térmico, composta de cimento cinzento, cargas minerais, resina redispersável em pó, fibras HD e aditivos especiais.	4,28	3,23
mt09mol080a	m	Perfil de arranque de alumínio.	1,14	0,83
mt09mol070a	m	Perfil de canto de alumínio.	0,96	0,70
mt16peb010b	m²	Painel rígido de poliestireno expandido (EPS), segundo NP EN 13163, de superfície lisa e bordo lateral recto, de 60 mm de espessura, cor cinzento, resistência térmica 1,35 m²°C/W, condutibilidade térmica 0,036 W/(m°C), densidade 20 kg/m³, Euroclasse E de reacção ao fogo, com código de designação EPS-NP EN 13163-L2-W2-T2-S2-P4-DS(N)2-BS170-CS(10)60-TR150.	9,03	5,96
mt16aaa021a	Ud	Bucha de expansão e prego de polipropileno, com aro de estanquidade, para fixação de placas isolantes.	0,48	0,30
mt28maw020	kg	Argamassa base weber.therm Base "WEBER CEMARKSA", para fixação e regularização de placas de isolamento térmico, composta de cimento cinzento, cargas minerais, resina redispersável em pó, fibras HD e aditivos especiais.	5,40	4,08
mt28mon040a	m²	Rede de fibra de vidro, de 10x10 mm de vão, anti-álcalis, de 200 a 250 g/m² de massa superficial e 750 a 900 microns de espessura, com 25 kp/cm² de resistência à tracção, para armar argamassas monomassa.	2,65	2,00
mt28mpc010aa1a	kg	Argamassa monomassa de ligantes mistos, para a impermeabilização e decoração de fachadas, Weber.pral Clima "WEBER CEMARKSA", acabamento raspado, cor Polar, composto de cimento branco, cal, resinas hidrófugas redispersáveis, inertes de granulometria compensada, aditivos orgânicos e pigmentos minerais. Segundo EN 998-1.	9,14	6,96
mt50spa200b600	Ud	Repercussão de montagem, utilização e desmontagem de andaimes homologados e meios de protecção, por m² de superfície executada de revestimento de fachada.	6,00	6,00
mo047	h	Oficial de 1ª montador de sistemas de fachadas pré-fabricadas.	12,11	10,47
mo090	h	Ajudante de montador de sistemas de fachadas pré-fabricadas.	11,76	10,17
	%	Meios auxiliares	1,23	0,99
	%	Custos indirectos	1,88	1,52
Custo total por m^2			66,06	53,21
Custo de manutenção decenal nos primeiros 10 anos por m^2			3,31	2,66

Table 37: Double glazing. Description and costs (CYPE 2013)

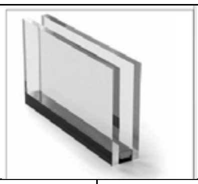
FVC010	**m^2**	**Vidro duplo.**		
Unitário	Ud	Descrição	Importância Edificio singolo	Importância todo bairro
mt21veu011aama	m^2	Vidro duplo Aislaglas "UNIÓN VIDRIERA ARAGONESA", conjunto constituído por vidro exterior Float incolor de 4 mm, caixa de ar desidratada com perfil separador de alumínio e dupla vedação perimetral, de 10 mm, e vidro interior Float incolor de 4 mm de espessura.	20,72	13,67
mt21sik010	Ud	Cartucho de silicone sintético incolor Elastosil WS-305-N "SIKA" de 310 ml (rendimento aproximado de 12 m por cartucho).	1,43	0,95
mt21vva021	Ud	Material auxiliar para a colocação de vidros.	1,26	0,83
mo050	h	Oficial de 1ª vidraceiro.	5,71	4,79
mo101	h	Ajudante de vidraceiro.	5,67	4,75
	%	Meios auxiliares	0,70	0,50
	%	Custos indirectos	1,06	0,76
Custo total por m^2			36,55	26,25
Custo de manutenção decenal nos primeiros 10 anos por m^2			7,68	5,51

Table 38: Window frame typology 80 X 120cm.Description and costs (CYPE 2013)

FCV010	**Ud**	**Caixilharia exterior de PVC "VEKA".**		
Unitário	Ud	Descrição	Importância Edificio singolo	Importância todo bairro
mt24vek010Acg	Ud	Janela de PVC "VEKA", sistema Softline Doble Junta SL/DJ, uma folha de abrir, dimensões 800x1200 mm, composta de aro, folha e bites com acabamento natural em cor branca, coeficiente de transmissão térmica do aro da secção tipo Uh,m = 1,3 W/(m^2°C), perfis de estética recta, espessura em paredes exteriores de 2,8 mm, 5 câmaras, reforços interiores de aço galvanizado, mecanizações de drenagem e descompressão, juntas de estanquidade de EPDM, puxador e ferragens bicromadas, Segundo NP EN 14351-1.	136,05	102,67
mt24pem010	m	Pré-aro para caixilharia exterior de PVC.	25,00	18,88
mt15sja100	Ud	Cartucho de pasta de silicone neutro.	0,63	0,50
mo016	h	Oficial de 1ª serralheiro.	29,09	24,44
mo054	h	Ajudante de serralheiro.	13,96	11,74
	%	Meios auxiliares	4,09	3,16
	%	Custos indirectos	6,26	4,84
Custo total por unidade			215,08	166,23
Custo de manutenção decenal nos primeiros 10 anos por unidade			19,36	14,96

Table 39: Window frame typology 200 X 120cm.Description and costs (CYPE 2013)

FCV010	**Ud**	**Caixilharia exterior de PVC "VEKA".**		
Unitário	Ud	Descrição	Importância Edificio singolo	Importância todo bairro
mt24vek020Alg	Ud	Janela de PVC "VEKA", sistema Softline Doble Junta SL/DJ, duas folhas de abrir, dimensões 2000x1200 mm, composta de aro, folhas e bites com acabamento natural em cor branca, coeficiente de transmissão térmica do aro da secção tipo Uh,m = 1,3 W/(m²°C), perfis de estética recta, espessura em paredes exteriores de 2,8 mm, 5 câmaras, reforços interiores de aço galvanizado, mecanizações de drenagem e descompressão, juntas de estanquidade de EPDM, puxador e ferragens bicromadas, Segundo NP EN 14351-1.	269,74	203,57
mt24pem010	m	Pré-aro para caixilharia exterior de PVC.	40,00	30,21
mt15sja100	Ud	Cartucho de pasta de silicone neutro.	0,63	0,50
mo016	h	Oficial de 1ª serralheiro.	25,00	21,00
mo054	h	Ajudante de serralheiro.	12,00	10,09
	%	Meios auxiliares	6,95	5,31
	%	Custos indirectos	10,63	8,12
Custo total por unidade			364,95	278,80
Custo de manutenção decenal nos primeiros 10 anos por unidade			32,85	25,09

Table 40: Insulation of the pitched roof: Description and costs (CYPE 2013)

NAQ030	m²	Isolamento de coberturas inclinadas sobre espaço não habitável.		
Unitário	Ud	Descrição	Importância Edificio singolo	Importância todo bairro
mt16lki020fgb	m²	Manta de lã mineral natural (LMN), revestida numa das suas faces com uma barreira de vapor constituída por papel kraft e polietileno, fornecida em rolos, Manta Kraft (TI 212) "KNAUF INSULATION", de 100 mm de espessura, segundo EN 13162, resistência térmica 2,5 m²°C/W, condutibilidade térmica 0,04 W/(m°C), Euroclasse F de reacção ao fogo, com código de designação MW-EN 13162-T1-Z2,2, de aplicação como isolante térmico e acústico entre muretes de coberturas inclinadas ou planas ventiladas, e sobre tectos falsos.	4,71	3,10
mt16aaa030	m	Fita autocolante para vedação de juntas.	0,30	0,20
mo049	h	Oficial de 1ª montador de isolamentos.	1,30	1,13
mo092	h	Ajudante de montador de isolamentos.	1,27	1,09
	%	Meios auxiliares	0,15	0,11

	%	Custos indirectos	0,23	0,17
Custo total por m^2			7,96	5,80
Custo de manutenção decenal nos primeiros 10 anos por m^2			0	0

ANNEX 3: ENERGY SIMULATION OF BUILDING TYPOLOGIES

In this annex will be present an overview on the neighborhood and the process of typification conducted in order to be ready to run the energetic simulations.

REAL SITUATION: IMAGES OF THE TYPOLOGIES

Figure 49: Typology A. Sub classes A1 and A2

Figure 50: Typology B. Sub classes B1 and B2

Figure 51: Typology C

TYPIFICATION OF THE TYPOLOGIES TO RUN THE ENERGY SIMULATION

In this section it will be presented the main configurations of the 3 typologies and the drawings of the models used to simulate them.

TYPOLOGY A

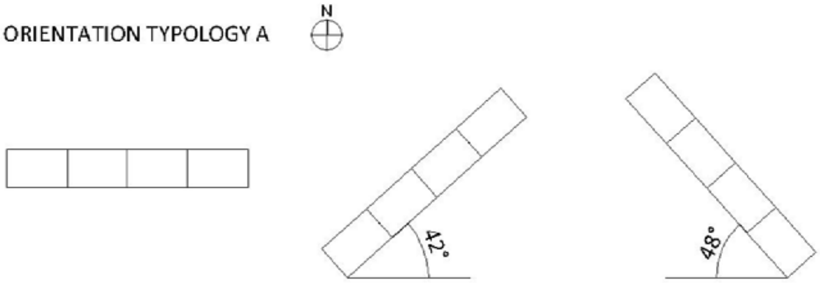


Figure 52: Main orientations typology A

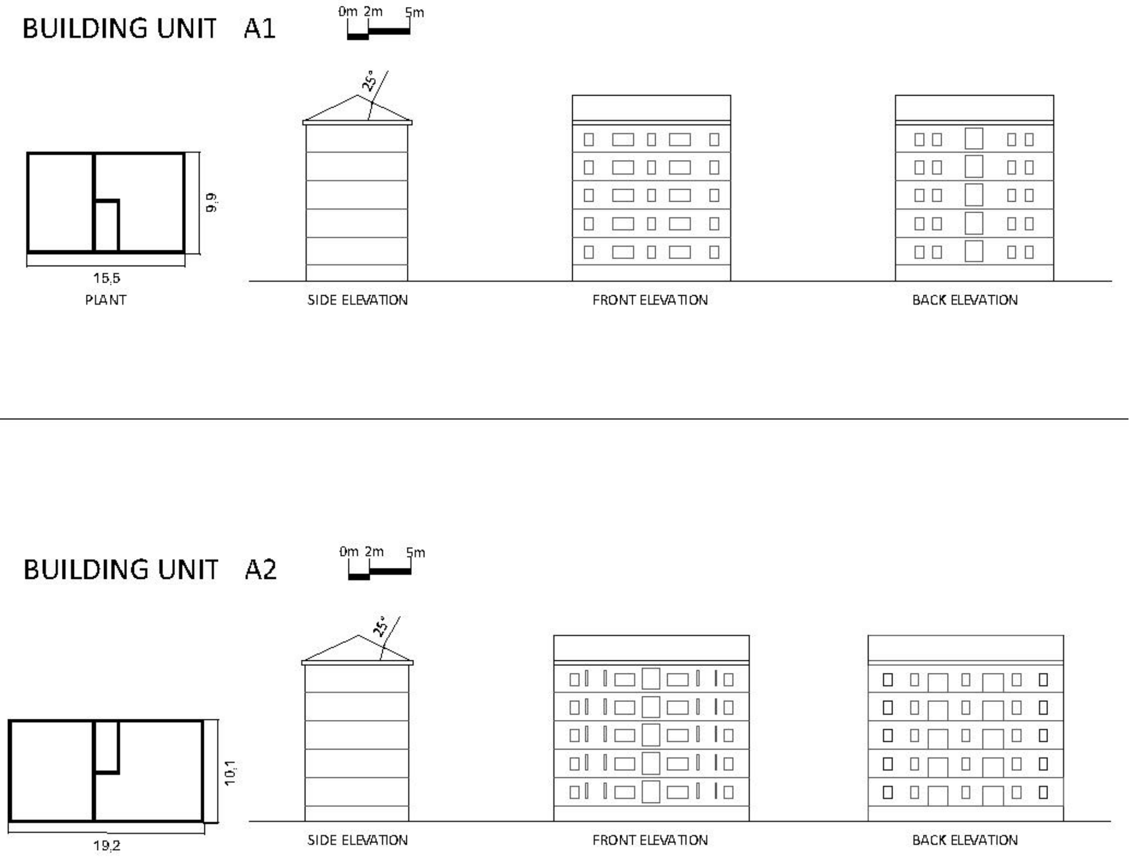


Figure 53: Representation of building units A1and A2 used for the simulation

TYPOLOGY B

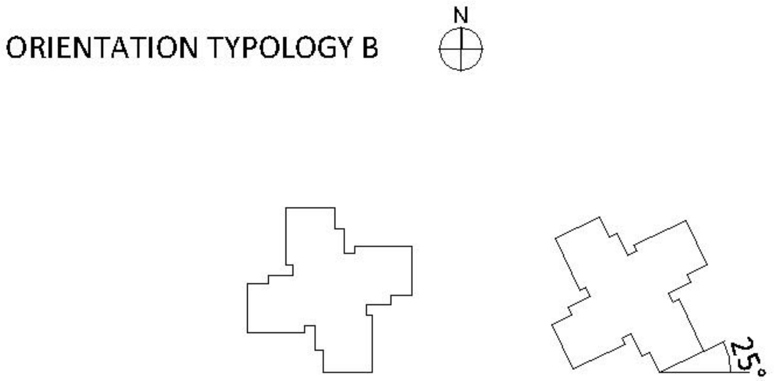


Figure 54: Main orientations typology B

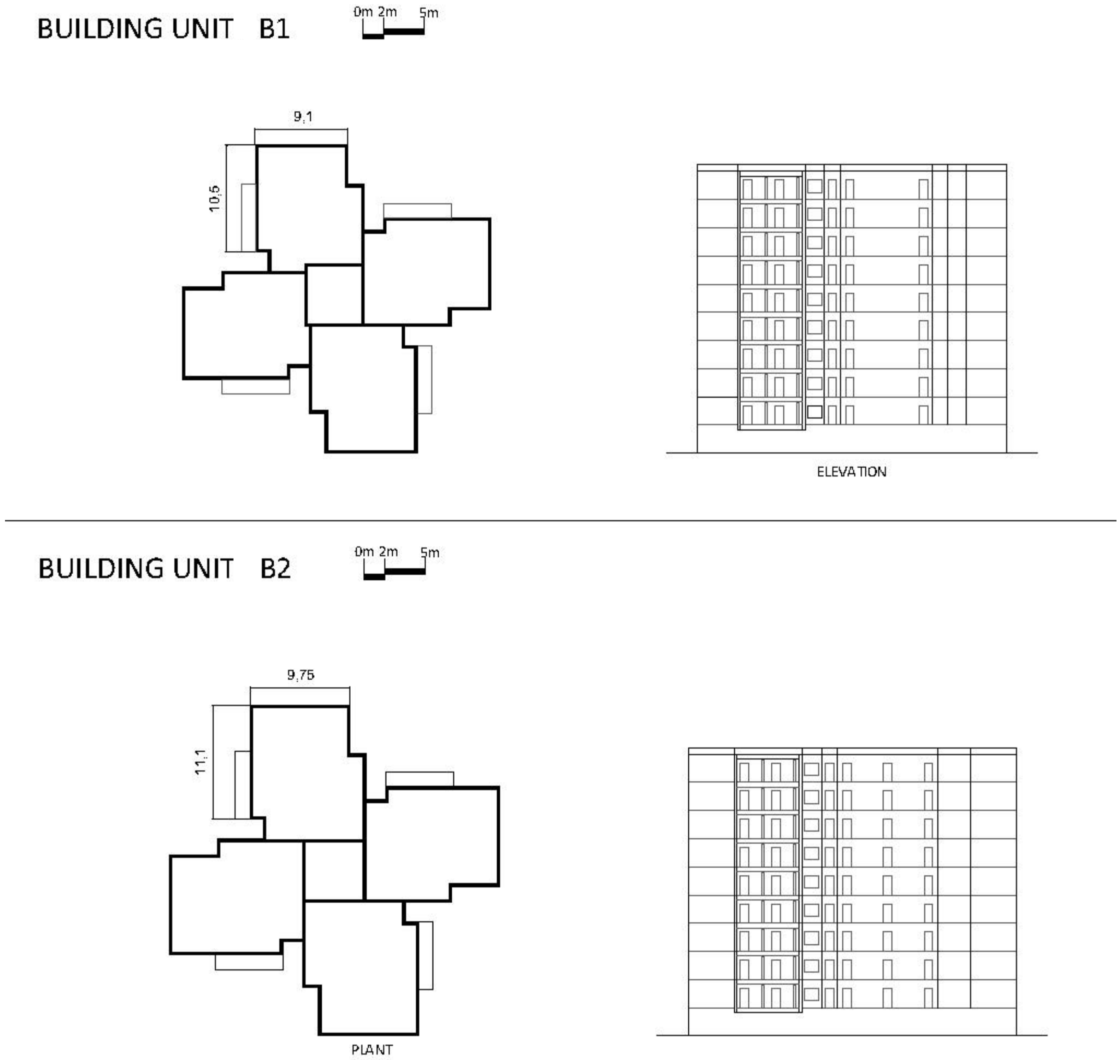


Figure 55: Representation of building units B1and B2 used for the simulation

TYPOLOGY C

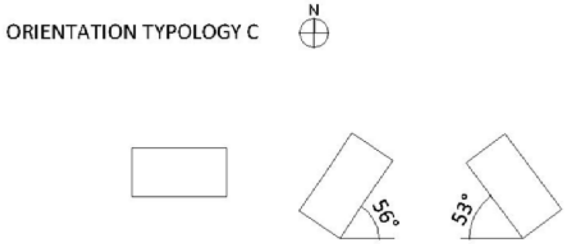


Figure 56: Main orientations typology C

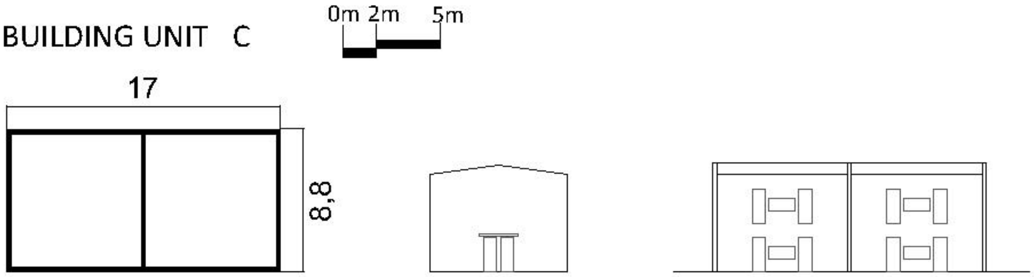


Figure 57: Representation of the building unit C used for simulation

DESIGN BUILDER MODELS FOR SIMULATION

TYPOLOGY A

Since typology A is a multi-family building in row the simulation has run considering two models, one representing the central unit, the building unit between two others units, and one representing the unit at the edges of the block . This choice is suggested by the fact that the unit at the edges and the central one differs in consumption since the units at the edges suffer of a higher exposition to the exterior conditions, having an higher exterior wall surface.

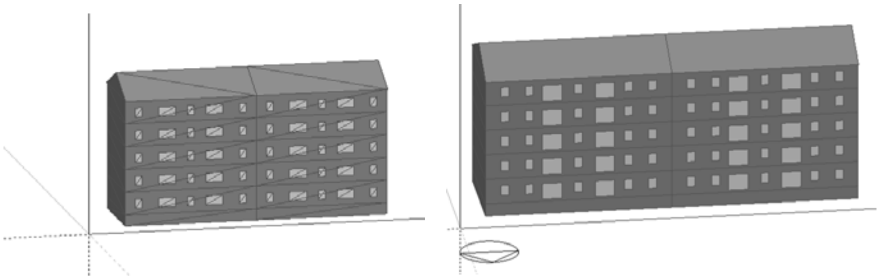


Figure 58: Edges typology A. Sub classes A1 and A2 (Source: Design Builder)

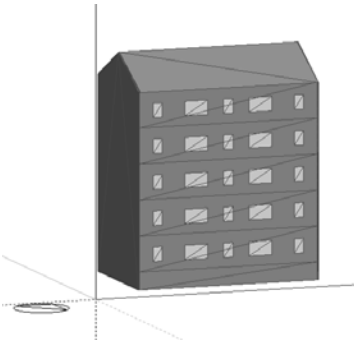


Figure 59: Building unit A. Sub classes A1 central position (Source: Design Builder)

TYPOLOGY B

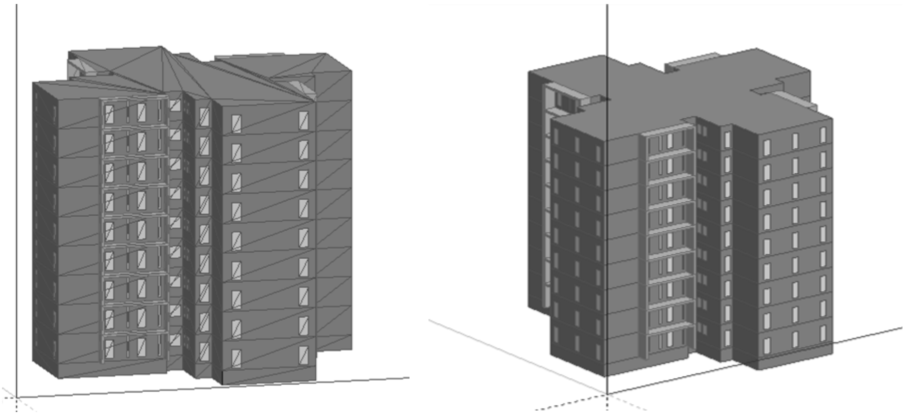


Figure 60: Typology B. Sub classes B1 and B2 (Source: Design Builder)

TYPOLOGY C

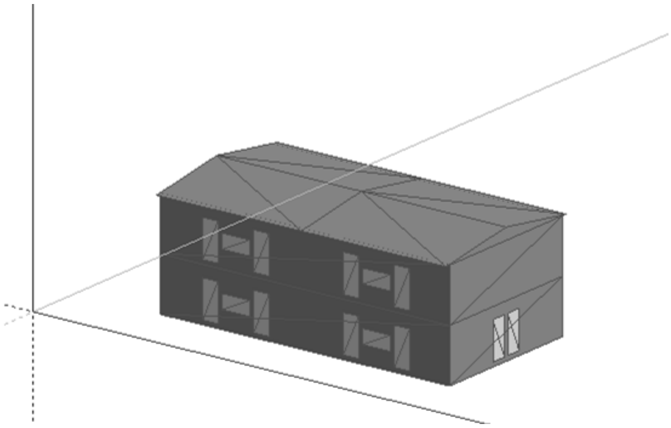


Figure 61: Typology C (Source: Design Builder)

RESULTS OF THE SIMULATIONS: CURRENT CONSUMPTIONS

Here follows the current consumption of the different configurations of the 3 typologies.

Table 41: Results of the simulation run with Design Builder of different configuration of the typology A

		Typology A			Typology A		
		A1	A2		A1	A2	
		Heating			Cooling		
		kWh/(m^{2}a)		Variation (%)	kWh/(m^{2}a)		Variation (%)
Orientation	N/S	73,2	74,6	2,0%	5,1	6,5	21,2%
	rot 42°	75,1	77,2	2,7%	6,9	9,2	24,6%
	rot -48°	75,6	77,9	2,9%	6,6	8,5	22,5%
	rot 180°	75,4	78,0	3,3%	4,7	5,9	20,1%
Variation (%)		3,3%	4,3%		32%	36%	

Table 42: Results of the simulation run with Design Builder of different configuration of the typology B

		Typology B			Typology B		
		B1	B2		B1	B2	
		Heating			Cooling		
		kWh/(m^2a)		Variation (%)	kWh/(m^2a)		Variation (%)
Orientation	N/S	88,16	86,18	2,2%	7,29	6,80	6,69%
	rot 25°	88,14			7,16		
Variation (%)		0,02%			1,73%		

Table 43: Results of the simulation run with Design Builder of different configuration of the typology B

		Typology C	
		Heating	Cooling
		kWh/(m^2a)	
Orientation	N/S	98,6	11,1
	rot 56°	100,8	13,2
	rot -53°	101,0	12,9
Variation (%)		2,3%	15,5%

Table 44: Recapitulation of the current consumption of the buildings chosen to represent the entire neighborhood

Simplification of the neighborhood		Typology		
		A	B	C
Heating	kWh/(m^2a)	75,1	88,2	98,6
Cooling		6,9	7,3	11,1

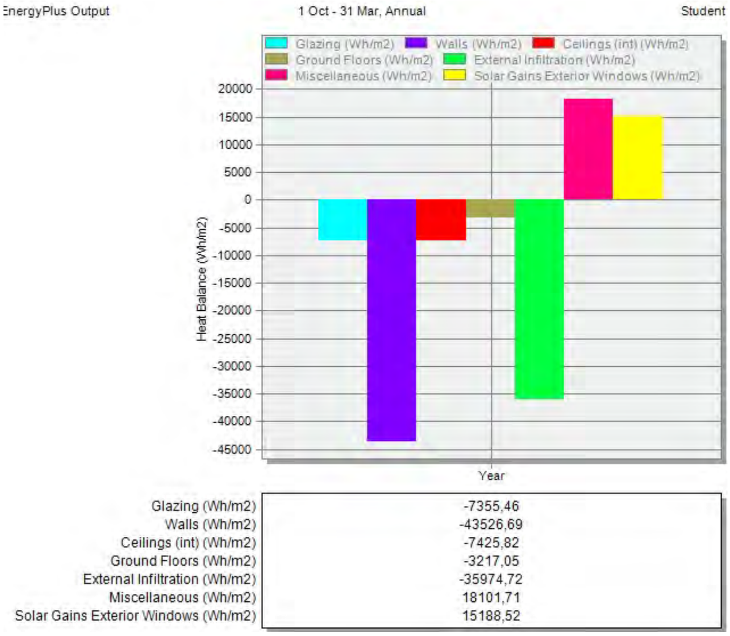
ANNEX 4: CONSUMPTION OF BUILDING UNIT A1 ROTATED 42°

In this annex it will be presented the detailed results of the building unit A1 rotated 42°, that is the unit chosen to represent all the buildings of the typology A of the neighborhood.

CONSUMPTION OF BUILDING A1 EDGES UNIT

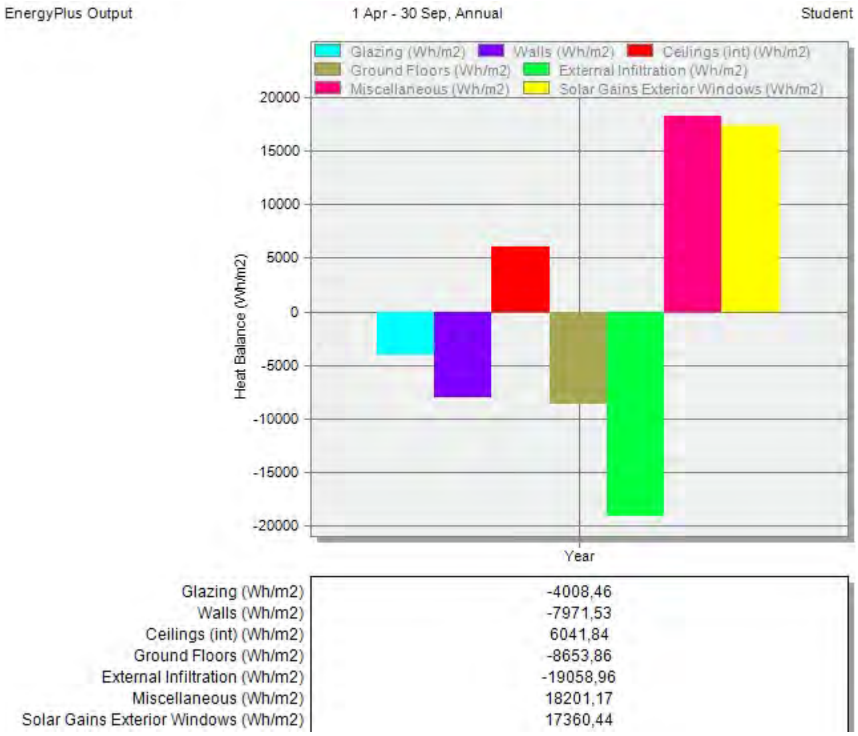
Heating (Electricity) (Wh/m2)	75138,52
Cooling (Electricity) (Wh/m2)	6941,56
DHW (Gas) (Wh/m2)	47815,82

Figure 62: Annual fuel breakdown to maintain comfort conditions edge unit (Source: Design Builder)



Glazing (Wh/m2)	-7355,46
Walls (Wh/m2)	-43526,69
Ceilings (int) (Wh/m2)	-7425,82
Ground Floors (Wh/m2)	-3217,05
External Infiltration (Wh/m2)	-35974,72
Miscellaneous (Wh/m2)	18101,71
Solar Gains Exterior Windows (Wh/m2)	15188,52

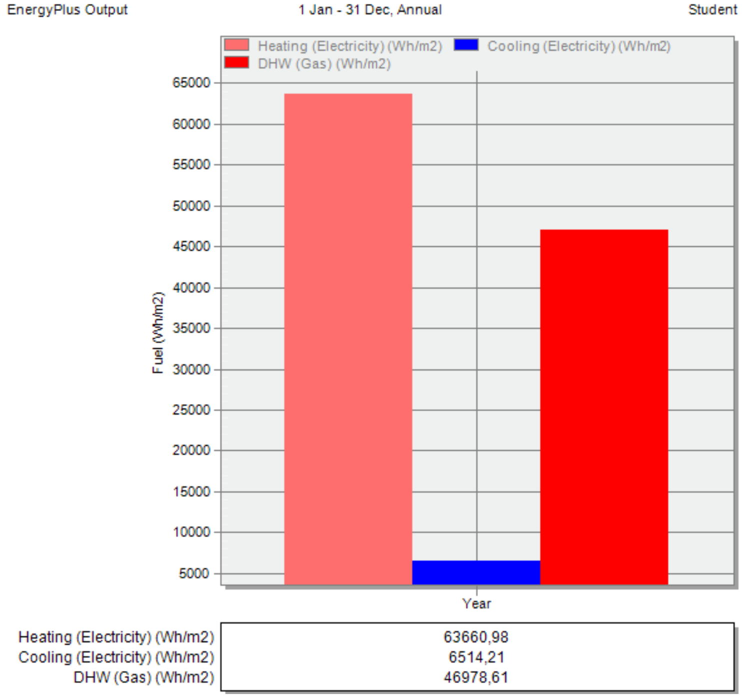
Figure 63 : Winter heat balance edge unit (Source: Design Builder)



Glazing (Wh/m2)	-4008,46
Walls (Wh/m2)	-7971,53
Ceilings (int) (Wh/m2)	6041,84
Ground Floors (Wh/m2)	-8653,86
External Infiltration (Wh/m2)	-19058,96
Miscellaneous (Wh/m2)	18201,17
Solar Gains Exterior Windows (Wh/m2)	17360,44

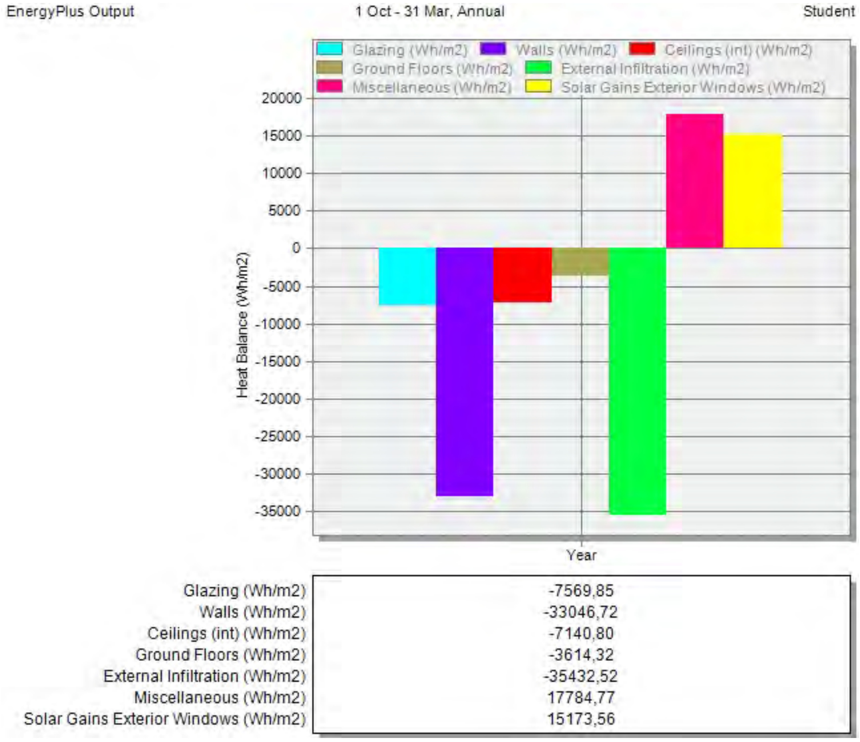
Figure 64: Summer heat balance edge unit (Source: Design Builder)

CONSUMPTION OF CENTRAL UNIT BUILDING A1



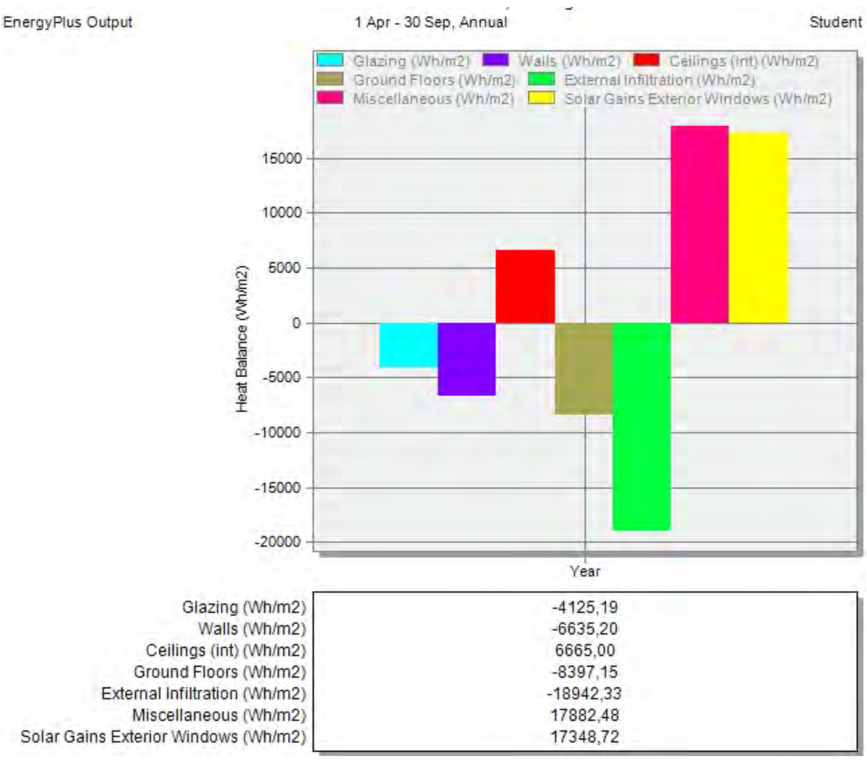
Heating (Electricity) (Wh/m2)	63660,98
Cooling (Electricity) (Wh/m2)	6514,21
DHW (Gas) (Wh/m2)	46978,61

Figure 65: Annual fuel breakdown to maintain comfort conditions (Source: Design Builder)



Glazing (Wh/m2)	-7569,85
Walls (Wh/m2)	-33046,72
Ceilings (int) (Wh/m2)	-7140,80
Ground Floors (Wh/m2)	-3614,32
External Infiltration (Wh/m2)	-35432,52
Miscellaneous (Wh/m2)	17784,77
Solar Gains Exterior Windows (Wh/m2)	15173,56

Figure 66: Winter heat balance (Source: Design Builder)



Glazing (Wh/m2)	-4125,19
Walls (Wh/m2)	-6635,20
Ceilings (int) (Wh/m2)	6665,00
Ground Floors (Wh/m2)	-8397,15
External Infiltration (Wh/m2)	-18942,33
Miscellaneous (Wh/m2)	17882,48
Solar Gains Exterior Windows (Wh/m2)	17348,72

Figure 67: Summer heat balance (Source: Design Builder)

ANNEX 5: REFURBISHMENT TYPOLOGY A: PASSIVE SOLUTIONS

In this annex will be presented the tables with the quantity of the materials needed to refurbish the neighborhood; and costs and savings of its implementation.

Quantification of materials

Table 45: Quantification of the typology A represented by building unit A1

Building typology	Sub class	Considering all the building as A1		
		Position	Number	Total net floor area (m^2)
A	A1	Central Unit	66	41794,5
		Edge unit	94	59525,5

Table 46: Quantification of the windows typologies for each unit

Window typology	Frame			Glazing			Number of windows each building unit
	Width (m)	Height (m)	A (m2)	Width (m)	Height (m)	A (m2)	
a	0,80	1,20	0,96	0,65	1,05	0,68	35
b	2,00	1,20	2,40	1,78	0,98	1,73	10

It has been chosen not to substitute the big windows on the stair case, because the stair case is a not conditioned space and so they don't influence significantly the heating and cooling loads of the apartments.

Table 47: Quantification of the materials needed for the refurbishment.

TIPOLOGY A			
Value for single unit			
		Lot coverage (m^2)	153,5
Walls (m^2)		Main façades (N+S)	350,5
		Edges façades (E+W)	295,5
Windows	a	Number	35
		Glazing area (m^2)	23,9
	b	Number	10
		Glazing area (m^2)	17,3

Values for the neighborhood			
		Number of blocks	47
		Number of buildings unit	160
		Lot coverage (m2)	24560
Walls (m2)			69969
Windows	a	Number	5600
		Glazing area (m^2)	3822
	b	Number	1600
		Glazing area (m^2)	2769

Cost of refurbishment

Table 48: Unit cost of the refurbishment solutions: normal and discounted price

Refurbishment solution	Unit	Value for single building		Value for whole neighborhood	
		Implementation cost (€/unit)	10 years O&M (€/unit)	Implementation cost (€/unit)	10 years O&M (€/unit)
6 cm ETIC (CYPE 2013)	m^2	€ 66,06	€ 3,31	€ 53,21	€ 2,66
10 cm roof insulation (CYPE 2013)	m^2	€ 7,96	€ 0,00	€ 5,80	€ 0,00
Window frame a (CYPE 2013)	un	€ 215,08	€ 19,36	€ 166,23	€ 14,96
Window frame b (CYPE 2013)	un	€ 364,95	€ 32,85	€ 278,80	€ 25,09
Double glass (CYPE 2013)	m^2	€ 36,55	€ 7,68	€ 26,25	€ 5,51

Table 49: Cost of refurbishment for the whole neighborhood with the normal market price

Refurbishment solution	Unit	Quantity	Implementation cost (€)	10 years O&M (€)
6 cm ETIC	m^2	69.968,5	€ 4.622.119,1	€ 231.595,7
10 cm roof insulation	m^2	24.560,0	€ 195.497,6	€ 0,0
Window frame A	un	5.600,0	€ 1.204.448,0	€ 108.416,0
Window frame B	un	1.600,0	€ 583.920,0	€ 52.560,0
Double glass	m^2	6.591,0	€ 240.901,1	€ 50.618,9

Table 50: Cost of refurbishment for the whole neighborhood thanks to the economy of scale

Refurbishment solution	Unit	Quantity	Implementation cost (€)	10 years O&M (€)
6 cm ETIC	m^2	69.968,5	€ 3.723.023,9	€ 186.116,2
10 cm roof insulation	m^2	24.560,0	€ 142.448,0	€ 0,0
Window frame A	un	5.600,0	€ 930.888,0	€ 83.776,0
Window frame B	un	1.600,0	€ 446.080,0	€ 40.144,0
Double glass	m^2	6.591,0	€ 173.013,8	€ 36.316,4

Savings due to refurbishment

Table 51: Consumption after refurbishment building A1.Central and edges units

Building Unit	Position	Loads	Unit	Current	With Etics	with roof insulation	Double glazing	Complete refurbishment
A1	Central	Heat	$kWh/(m^2a)$	63,7	37,5	58,2	54,0	21,6
		Cool	$kWh/(m^2a)$	6,5	6,3	5,2	6,9	6,0
		Tot	$kWh/(m^2a)$	70,2	43,9	63,4	60,9	27,5
		Savings	$kWh/(m^2a)$		26,3	6,7	9,3	42,6
		Red	%		37%	10%	13%	61%
	Edges	Heating	$kWh/(m^2a)$	75,1	40,4	69,8	65,4	24,3
		Cooling	$kWh/(m^2a)$	6,9	6,2	5,8	7,2	5,8
		Tot	$kWh/(m^2a)$	82,1	46,6	75,6	72,6	30,1
		Savings	$kWh/(m^2a)$		35,5	6,5	9,4	52,0
		Red	%		43%	8%	11%	63%

Table 52: Quantification typology A represented by unit A1

Building Unit	Position	Number	Total floor area (m2)
A1	Central	66	41794,5
	Edge	94	59525,5

Table 53: Quantification saving for all the typology A of the neighborhood

Refurbishment solution	Building position	Saving/m^2	Neighborhood savings		
		kWh/(m^{2}a)	kWh/a	kWh/a	€/a
6 cm ETIC	Central	26,3	1.099.208,0	3.211.561,9	€ 529.907,7
	Edge	35,5	2.112.353,9		
10 cm roof insulation	Central	6,7	281.579,8	666.394,5	€ 109.955,1
	Edge	6,5	384.814,7		
Double glazing	Central	9,3	386.853,2	948.661,9	€ 156.529,2
	Edge	9,4	561.808,7		
Complete refurbishment	Central	42,6	1.781.650,1	4.877.874,7	€ 804.849,33
	Edge	52,0	3.096.224,6		

ANNEX 6: LIST OF PHOTOVOLTAIC AND SOLAR SYSTEM SOLUTIONS

In this annex will be presented the result of the market research conducted to choose a photovoltaic and solar system within a range of alternative solutions. The solutions have been identified resorting to the experience of technicians that install or provide these systems and through the generator of price http://www.geradordeprecos.info/.

Table 54: List of photovoltaic systems due to the market research

ANALYSIS OF THE PHOTOVOLTAIC MARKET			
COUNTRY	SOURCE	Gen Price (€/kWp)	Model suggested
Europe	(EPIA 2010)	2500-3500	
Europe	(EPIA 2012)	1700-2300	
Italy	energiaarcobaleno.it	2200-2800	Solsonica - Siliken - Conergy 250 Wp
Italy	Studio Negri & Fauro Architetti Associati	2000-3000	Solarworld poly 250Wp
Italy	SUSIN & C. s.a.s.	2454-2636	Centrosolar S-Class Integration / Deluxe
Portugal	microgeracaoedp.com	2120-2199	European brands
Portugal	Selfenergy	2173 - 2310	Fluitecnik FTS-220P /painéis Suntech STP220-20Wd

Table 55: List of solar thermal systems due to the market research

ANALYSIS OF THE SOLAR THERMAL MARKET			
COUNTRY	SOURCE	Gen Price (€/m2)	Model
Italy	TECHNE ENEGHEIA	900	VAILLANT AuroTherm plus 250l (includes also boiler) FLAT PANEL
Portugal	(CYPE 2013)	1090	Logasol SC/2/SKS/SU300
Portugal	(CYPE 2013)	970	DB-300 "LUMELCO"
Portugal	(CYPE 2013)	912	Helioconcept 300 TM2-P "SAUNIER DUVAL"
Italy	TECHNE ENEGHEIA	1413	VAILLANT AuroTherm exclusiv 250l VACUM TUBE
Portugal	(CYPE 2013)	1719	Thermomax Kingspan Solar - DF 100-30 Direct Flow

ANNEX 7: SIZING OF THE ACTIVE SYSTEMS: PHOTOVOLTAIC AND SOLAR THERMAL

PHOTOVOLTAIC

Sizing methodology

To size the photovoltaic system has been used the equation:

$$E_{el} = \sum_{i=1}^{12} h_{eq} * P_{el,p} * N_i * R * TCF_i$$

TCF_i is the parameter that takes into account the variation of the efficiency of the cell due to the fact that it is not working at the design temperature of 25°C.

$$TCF_i = 1 + \Delta P_m$$

$\Delta P_m(\%) = C_t * (T_{cell} - 25)$ is the percentage variation from the nominal efficiency.

For its calculation is necessary to calculate the real temperature of the cell Tcell and Ct that is a value given by the producer of the system and represent the %variation of efficiency for each °C of variation from 25°C.

The real temperature of the cell can be calculated with the following equation

$$T_{cell} = T_{ext} * G * \frac{T_{NOCT} - 20}{800}$$

where T_{ext} is the daily outside temperature, T_{NOCT} a value given by the producer of the photovoltaic system chosen, and G the power of solar radiation reaching the surface.

Sizing of the photovoltaic system in Mira Sintra

Table 56: Characteristics photovoltaic system chosen

Model	Price (€/kWp)	Wp	NOCT (°C)	Ct	efficiency %	A (m^2)
Fluitecnik FTS-240P	2241	240	46	-0,0045	14,75%	1,63

Table 57: Calculation of the variation of efficiency due to the cell temperature (TCFi)

	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T ext	10,8	11,9	14,5	15,9	18,5	22,1	23,9	24,3	22,2	18,8	14,4	11,5
H_m(25°) (kWh/m2/day)	3,30	4,32	5,57	6,33	6,76	7,21	7,32	7,14	6,41	4,95	3,83	3,11
Duration average day (h)	9,0	10,0	11,5	12,5	13,5	14,0	14,0	13,0	12,0	10,5	9,5	9,0
G_m(25°) (W/m^2)	367	432	484	506	501	515	523	549	534	471	403	346
T_{cell} (°C)	22,7	25,9	30,2	32,4	34,8	38,8	40,9	42,2	39,6	34,1	27,5	22,7
ΔP_m (%)	0,01	0,00	-0,02	-0,03	-0,04	-0,06	-0,07	-0,08	-0,07	-0,04	-0,01	0,01
TCF_i	1,01	1,00	0,98	0,97	0,96	0,94	0,93	0,92	0,93	0,96	0,99	1,01

Table 58: Calculation of the monthly electricity generation

	Jan	Feb	Mar	Apr	Mar	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$P_{el,p}$ (kW)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
h_{eq} (h)	3,30	4,32	5,57	6,33	6,76	7,21	7,32	7,14	6,41	4,95	3,83	3,11
$N_{gg,i}$ (day)	31	28	31	30	31	30	31	31	30	31	30	31
R	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
TCF_i	1,01	1,00	0,98	0,97	0,96	0,94	0,93	0,92	0,93	0,96	0,99	1,01
$E_{el,i}$ (MWh)	223,2	260,2	364,2	396,6	432,7	438,1	455,1	441,2	388,2	317,9	245,4	210,4

With 2,7MW_p the system produces 4173,09MWh/a thus covering the entire annual request of 4101,85 MWh.

SOLAR THERMAL

SIZING METHODOLOGY

To size the photovoltaic system it has been used the methodology.

To estimate the surface of the solar collector needed it has been used the equation:

$$A_c = \frac{Q_{HW}}{Energy\ flow\ absorbed} = \frac{Q_{HW}}{\eta_m * H_m}$$

with $Q_{HW} = V_{DHW} * C_w * \Delta T$ is the energy needed to heat the water daily required to 60°

$\eta_m = \eta_o - a_1 * X - a_2 * G * X^2$ is the efficiency of the collector in real use condition , reduced by the fact that real conditions differ from the design conditions considered by the producer.

η_o is the efficiency at design condition and a_1 and a_2 reduction efficiencies parameters. All these values are given in the technical data by the collector producer.

$X = \frac{(tm-ta)}{G}$ is a variable to quantify the variation from the design conditions.

FLAT SOLAR COLLECTOR

Table 59: Characteristics flat solar collector chosen

Model	Price (€/m^2)	η_o	a_1(W/m^2K)	a_2(W/m^2K)	Ac (m^2)	A_{tot} (m^2)
Valliant auto plus	900	0,832	3,297	0,017	2,33	2,5

Table 60: Calculation of the daily energy required to heat the water

V_{DHW} (l/day)	Cw (Wh/kg°C)	$T_{cold\ water}$ (°C)	$T_{hot\ water}$ (°C)	$\Delta T_{hot-cold\ (°C)}$	Q_{HW} (kWh/day)
122,60	1,16	15	60	45	6399,6

Table 61: Calculation monthly average efficiency of the collector (η_m)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
text (°C)	10,8	11,9	14,5	15,9	18,5	22,1	23,9	24,3	22,2	18,8	14,4	11,5
tu (°C)	60	60	60	60	60	60	60	60	60	60	60	60
ti (°C)	45	45	45	45	45	45	45	45	45	45	45	45
tm (°C)	52,5	52,5	52,5	52,5	52,5	52,5	52,5	52,5	52,5	52,5	52,5	52,5
Gm(25°) (W/m^2)	367	432	484	506	501	515	523	549	534	471	403	346
X ((m^2°C)/W)	0,11	0,09	0,08	0,07	0,07	0,06	0,05	0,05	0,06	0,07	0,09	0,12
η_m	0,38	0,46	0,52	0,55	0,57	0,61	0,63	0,64	0,62	0,56	0,46	0,36

Table 62: Calculation of collector surface needed to satisfy the monthly request

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hm(25°) (kWh/m^2/day)	3,30	4,32	5,57	6,33	6,76	7,21	7,32	7,14	6,41	4,95	3,83	3,11
η_m	0,38	0,46	0,52	0,55	0,57	0,61	0,63	0,64	0,62	0,56	0,46	0,36
A (m^2)	5152	3240	2198	1842	1664	1462	1398	1405	1621	2328	3639	5746

Table 63: Calculation of the energy produced, chosen a fixed surface of solar collector

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ac	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
E req (kWh/day)	6400	6400	6400	6400	6400	6400	6400	6400	6400	6400	6400	6400
E prod kWh/day)	1739	2766	4076	4863	5384	6126	6406	6378	5526	3849	2462	1559
E used (kWh/day)	1739	2766	4076	4863	5384	6126	6400	6378	5526	3849	2462	1559

Table 64: Calculation of the solar fraction covered with solar thermal

E req (MWh/a)	E used (MWh/a)	Solar fraction
2335,8	1557,7	67%

VACUUM TUBE SOLAR COLLECTOR

The calculations of the vacuum tube system will not be presented in detail. The results can be found in the discussion of the solar thermal in the thesis.

The sizing of the vacuum tube has been conducted with the same methodology using the following technical data:

Table 65: Characteristics vacuum tube solar collector chosen

Model	Price (€/m^2)	η_o	a_1(W/m^{2}K)	a_2(W/m^{2}K)	Ac (m^2)	A_{tot} (m^2)
Thermomax DF100-20	1719	0,832	1,14	0,0144	3,23	4,25

ANNEX 8: FEASIBILITY STUDY OF THE SOLUTIONS PROPOSED

In this annex will be presented the Excel tables with detailed calculation of the feasibility of some of the solutions proposed (passive and active) with normal and discounted purchase price.

FEASIBILITY OF THE 6cm ETICS

With normal market price (without benefit of the discount due to the scale)

Table 66: Study of the feasibility of ETIC with normal market price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Investment (k€)	-4622																														
O&M cost (k€)											-232										-232										
Annual savings (k€)		530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530
Cash flow (k€)	-4622	530	530	530	530	530	530	530	530	530	298	530	530	530	530	530	530	530	530	530	298	530	530	530	530	530	530	530	530	530	530
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-4622	505	481	458	436	415	395	377	359	342	183	310	295	281	268	255	243	231	220	210	112	190	181	173	164	156	149	142	135	129	123
Cumulated cash flow (k€)	-4622	-4117	-3637	-3179	-2743	-2328	-1932	-1556	-1197	-856	-672	-363	-68	213	481	736	979	1210	1430	1640	1752	1942	2124	2296	2460	2617	2766	2908	3043	3172	3294
NPV (k€)	3294																														
Time Payback (years)	12-13																														

With discounted price due to the economy of scale

Table 67: Study of the feasibility of ETIC with discounted price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Investment (k€)	-3723																														
O&M cost (k€)											-186										-186										
Annual savings (k€)		530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530	530
Cash flow (k€)	-3723	530	530	530	530	530	530	530	530	530	344	530	530	530	530	530	530	530	530	530	344	530	530	530	530	530	530	530	530	530	530
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-3723	505	481	458	436	415	395	377	359	342	211	310	295	281	268	255	243	231	220	210	130	190	181	173	164	156	149	142	135	129	123
Cumulated cash flow (k€)	-3723	-3218	-2738	-2280	-1844	-1429	-1033	-657	-298	43	255	564	859	1140	1408	1663	1906	2137	2357	2567	2696	2887	3068	3240	3405	3561	3710	3852	3987	4116	4239
NPV (k€)	4239																														
Time Payback (years)	8-9																														

Similarly has been calculated the NPV and the time payback for the substitution of the windows and the insulation of the roof, whose calculation are not presented in detail.

FEASIBILITY OF THE COMPLETE REFURBISHMENT (ETIC+WINDOWS+ROOF INSULATION)

With normal market price (without benefit of the discount due to the scale)

Table 68: Study of the feasibility of complete refurbishment with normal market price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Investment (k€)	-6847																														
O&M cost (k€)											-443										-443										
Annual savings (k€)		805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805
Cash flow (k€)	-6847	805	805	805	805	805	805	805	805	805	362	805	805	805	805	805	805	805	805	805	362	805	805	805	805	805	805	805	805	805	805
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-6847	767	730	695	662	631	601	572	545	519	222	471	448	427	407	387	369	351	334	319	136	289	275	262	250	238	226	216	205	196	186
Cumulated cash flow (k€)	-6847	-6080	-5350	-4655	-3993	-3362	-2762	-2190	-1645	-1126	-904	-434	15	441	848	1235	1604	1955	2289	2608	2744	3033	3308	3570	3820	4058	4284	4499	4705	4900	5087
Net present value (k€)	5087																														
Time Payback (years)	11-12																														

With discounted price due to the economy of scale

Table 69: Study of the feasibility of complete refurbishment with discounted price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Investment (k€)	-5415																														
O&M cost (k€)											-346										-346										
Annual savings (k€)		805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	805	804,85
Cash flow (k€)	-5415	805	805	805	805	805	805	805	805	805	458	805	805	805	805	805	805	805	805	805	458	805	805	805	805	805	805	805	805	805	804,85
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-5415	767	730	695	662	631	601	572	545	519	281	471	448	427	407	387	369	351	334	319	173	289	275	262	250	238	226	216	205	196	186
Cumulated cash flow (k€)	-5415	-4649	-3919	-3224	-2561	-1931	-1330	-758	-214	305	587	1057	1505	1932	2339	2726	3095	3446	3780	4099	4272	4560	4836	5098	5347	5585	5811	6027	6232	6428	6614
NPV (k€)	6614																														
Time Payback (years)	8-9																														

FEASIBILITY PHOTOVOLTAIC SYSTEM

With normal market price (without benefit of the discount due to the scale)

Table 70: Study of the feasibility of photovoltaic with normal market price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment (k€)	-6051																									
O&M cost (k€)		-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61	-61
Annual savings (k€)		689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689
Annual savings after reduction of efficiency (k€)		689	682	675	668	661	654	647	640	633	627	620	613	606	599	592	585	578	572	565	558	551	544	537	530	523
Cash flow (k€)	-6051	689	682	675	668	661	654	647	640	633	627	620	613	606	599	592	585	578	572	565	558	551	544	537	530	523
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-6051	656	618	583	549	518	488	460	433	408	385	362	341	321	303	285	268	252	237	223	210	198	186	175	164	155
Cumulated cash flow (k€)	-6051	-5395	-4777	-4194	-3644	-3126	-2638	-2178	-1745	-1336	-952	-589	-248	73	376	661	929	1181	1418	1642	1852	2050	2236	2411	2575	2730
NPV (k€)	2730																									
Time Payback (years)	12-13																									

With discounted price due to the economy of scale

Table 71: Study of the feasibility of photovoltaic with discounted price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment (k€)	-4387																									
O&M cost (k€)		-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44	-44
Annual savings (k€)		689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689
Savings after annual reduction of efficiency (k€)		689	682	675	668	661	654	647	640	633	627	620	613	606	599	592	585	578	572	565	558	551	544	537	530	523
Cash flow (k€)	-4387	645	638	631	624	617	610	603	596	590	583	576	569	562	555	548	541	535	528	521	514	507	500	493	486	479
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-4387	614	579	545	513	484	455	429	404	380	358	337	317	298	280	264	248	233	219	206	194	182	171	161	151	142
Cumulated cash flow (k€)	-4387	-3773	-3194	-2649	-2136	-1652	-1197	-768	-364	16	373	710	1027	1325	1605	1869	2117	2350	2570	2776	2969	3151	3322	3483	3634	3775
NPV (k€)	3775																									
Time Payback (years)	8-9																									

FEASIBILITY SOLAR THERMAL SYSTEM

FLAT COLLECTOR

With normal market price (without benefit of the discount due to the scale)

Table 72: Study of the feasibility of flat solar collectors with normal market price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment (k€)	-1260																									
O&M cost (k€)		-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13
Annual savings (k€)		179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179
Cash flow (k€)	-1260	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167	167
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-1260	159	151	144	137	131	124	118	113	107	102	97	93	88	84	80	76	73	69	66	63	60	57	54	52	49
Cumulated cash flow (k€)	-1260	-1101	-950	-806	-669	-538	-414	-295	-182	-75	27	125	218	306	390	470	547	620	689	755	818	878	935	989	1040	1090
NPV (k€)	1090																									
Time Payback (years)	9-10																									

With discounted price due to the economy of scale

Table 73: Study of the feasibility of flat solar collectors with discounted price

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Investment (k€)	-774,9																									
O&M cost (k€)		-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Annual savings (k€)		179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179	179
Cash flow (k€)	-774,9	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172	172
r (discount rate)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Present cash flow (k€)	-775	163	156	148	141	134	128	122	116	111	105	100	96	91	87	83	79	75	71	68	65	62	59	56	53	51
Cumulated cash flow (k€)	-775	-612	-456	-308	-167	-32	96	218	334	445	550	650	746	837	923	1006	1085	1159	1231	1299	1363	1425	1483	1539	1593	1643
NPV (k€)	1643																									
Time Payback (years)	5-6																									

Similarly it has been assessed the feasibility of the vacuum tube. It will not be presented in detail the tables with the sizing.

The results have been discussed in the exposition of the dissertation.