# Cost optimal strategies for the renovation of residential neighbourhoods towards energy and emissions neutrality – Rainha Dona Leonor case study

Marco Ferreira
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, State/Province, Portugal
marcoferreira@civil.uminho.pt

Manuela Almeida
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, State/Province, Portugal
malmeida@civil.uminho.pt

Ana Rodrigues
University of Minho, School of Engineering, Department of Civil Engineering, Guimarães, State/Province, Portugal
anarocha32846@yahoo.co.uk

ABSTRACT: Buildings are one of the major consumers of energy in Europe. This makes them an important target when aiming to reduce the energy consumptions and carbon emissions. The majority of the European building stock has already some decades and so it needs renovation in order to keep its functionality. Taking advantage of these interventions, the energy performance of the buildings may also be improved. In Portugal the renovation techniques, both regarding energy efficiency measures as well as measures for the use of renewable energy sources, are normally planned at the building scale. It is important to explore the possibility of having large scale interventions, has it has been done in other countries, namely at neighbourhood scale with district energy system in order to optimize the results in terms of costs and environmental impact.

**Keywords:** European Building Stock; Energy Performance of Buildings; Cost Optimal Strategies; residential renovation

## 1 INTRODUCTION

Climate changes are affecting peoples' life and are expected to severely increase their impact over the next years. In Europe, the European Commission has been taking some measures in order to mitigate the climate changes. Most of these measures are regulations which aim at reducing the greenhouse gas emissions. One of these policies is known as the 20-20-20 (EC, 2008). The 20-20-20 targets consist of reducing the primary energy consumption by 20%, reducing the carbon emissions by 20% and increasing the contribution of renewable energy by 20%, until 2020 (CEC, 2008). Besides this, there is also the intention of increasing the interconnection of the electric net among the EU member states by 10% (European Commission, 2014). In the meantime, other targets have been set for 2030, such as reducing the greenhouse gas emissions by 40%, when comparing with 1990 values, increase the energy efficiency in 27%, increase the contribution of the renewable energy in 27% and finally increasing the completion of the internal energy market by developing an electricity interconnection between the member states of 15% (EC, 2014). To achieve these values it is necessary to act in different sectors, such as transports, buildings, agriculture, electricity production and industry (EC, 2011). Buildings sector is one of the sectors that presents a great potential for reducing the carbon emissions, of around 90% below 1990 levels until 2050 (EC, 2011).

The building sector represents a long-lasting physical capital and any measures taken or not taken today will leave a legacy for many decades to come. There is some evidence that updates and mandatory energy-efficiency standards in buildings are the most effective instruments to increase the energy efficiency. These standards may refer to different elements of a building (UN, 2011). As an example, the European Commission made public a mandatory regulation for all member states, the Energy Performance of Buildings Directive, EPBD (EP/EC, 2010), that introduces two main concepts, namely, cost-optimal energy performance and nearly-zero energy buildings. The cost-optimal energy performance is regulated by a common methodology framework to evaluate the cost effectiveness of the constructive solutions for buildings or buildings elements, which balances the global costs of renovation with energy needs that come from a certain renovation process. The nearly zero building is a concept mainly related to buildings with very low energy needs. The EPBD states that each member state should define their requirements to classify a building as nearly zero (EP/EC, 2010).

Despite the fact the energy performance of buildings depends much on the systems for heating, cooling and DHW, the buildings envelope must not be underestimated, once it reduces the temperature exchanges with the outside environment, contributing not only to the optimized performance of the systems (OECD/IEA, 2013) but also to a better indoor environment. The roadmap 2050, states that a balance between an efficient envelope and advanced equipment needs to be established at the regional or local level (OECD/IEA, 2013).

In what concerns the systems for heating, cooling and DHW, and considering they are responsible for the biggest amount of energy consumption within buildings energy use, it is predicted that energy efficient heating and cooling technologies have the potential of reducing $CO_2$ emissions by up to 2 Gt by 2050. These technologies may include solar thermal, combined heat and power (CHP), heat pumps and thermal energy storage, photovoltaic, urban wind energy and biomass (OECD/IEA, 2011).

According to OECD and IEA, district heating is the most energy-efficient heating solution in densely-built areas. In rural areas, where there are mostly detached houses, the heating systems will be replaced by heat pumps, electric heating and wood fuels (OECD/IEA, 2011).

The key to answer to the current energy demands with their consequent carbon emissions seems to be the use of renewable sources of energy, such as hydroelectric, wind, solar photovoltaic, solar thermal or geothermal. These types of energy sources do not involve direct greenhouse gas emissions (UN, 2011).

The problem is when the intervention at building scale is constrained by the buildings specific characteristics or low cost effectiveness, not allowing the introduction of some technics which are available for new buildings. This situation is encouraging some cities to go to the next level on the effort of achieving more energy efficient buildings by using district energy systems. The increase in the energy efficiency of the neighbourhood always depend on the energy mix. However, it can help to increase the efficiency in about 20% considering the neighbourhoods buildings as a whole. District energy systems creates the opportunity of reducing the carbon emissions and increases the energy efficiency in buildings in ways that could not be possible when done at building scale, especially when renewable energy sources are involved.

To better understand the potential of energy performance improvement on existing buildings using the district energy technologies, namely renewable energy sources, the case of a social neighbourhood has been analysed. Based on the cost-optimal methodology, following the Delegated Regulation nº 244/2012 (EC, 2012), the cost-optimal solutions including renewable systems at building and district scales, are compared.

## 2 DISTRICT TECHNOLOGIES FOR HEATING, COOLING AND DHW

From the energy production until the final consumer a great amount of energy is lost by conversion. These losses affect seriously the balance between the energy supply and the energy consumption. In the European Union 30% of the energy is used in transformation before it is available for consumption. According to the European Environment Agency, in 2009, conventional power plants had an average transformation efficiency of 50% (EEA, 2014). If the efficiency levels of the energy conversion increase 75%, 10% of the EU greenhouse gas emissions could be avoided (EEA, 2014).

Most of the times the buildings systems are designed to be applied at the building scale (a single house or fractions). However, the neighbourhood scale is gaining its role in the energy efficiency issues. The current Combined Heat and Power plants (CHP) also known as co-generation, are gaining relevance in district energy systems (UN, 2011). The district technologies may include a variety of fuels, such as biomass, surplus heat, wastes, solar and wind (IDEA, 2012). For example, the waste incineration, releases steam which is used to heat and cool water that circulates in pipes and then it is connected to buildings heating/cooling grids. Another possibility is geothermal fields, which take advantage of the earth heat. The heat is brought to surface by underground water circulation and by intrusion into earth's crust. A geothermal plant pumps the steam or hot water from the cavities beneath the earth surface (RNP, 2014). Biomass can also generate electricity and combined heat and power via steam turbines in the power plants. Generally this plants are ten times smaller than coal plants, but it all depends on the size of the district it has to serve. These technologies are used to dispose large amounts of residues and wastes. With the right quality of wood chips in modern CHP plants, electric efficiency can reach 34% (IEA, 2007). Another technology that is used is the district solar energy, which uses the solar irradiance to produce electricity using photovoltaic panels and concentrating solar power to produce thermal energy. There is also the wind energy, where electricity is produced by the use of wind turbines located onshore or offshore (IPCC, 2012).

These district technologies have led to the creation of neighbourhood concepts such has: energy positive neighbourhood and carbon neutral communities. The first concept is when the neighbourhood generates more energy from renewable sources than it consumes. The surplus energy is exported or stored. In what concerns carbon emissions, these neighbourhoods show a significant decrease on their values. The second concept is when the neighbourhood has zero carbon emissions due to on-site energy production based on renewable energy sources.

Cases like the Western Harbour, Malmo, Sweden, where the thermal aquifer was used to supply energy to the buildings are good examples of it. The aquifer system is supported by heat pumps for heating and cooling and also cooling machines. The system produces 3900MWh heating per year and 3400MWh cooling per year. To supply electricity in the near-by areas, wind power and photovoltaics are being used (INTERREG/IVC, 2014).

The BedZED in the United Kingdom uses wood-fuelled combined heat and power plant. It is an example of small scale carbon neutral technologies. Figure 1 shows the general scheme of combined biomass power plant.

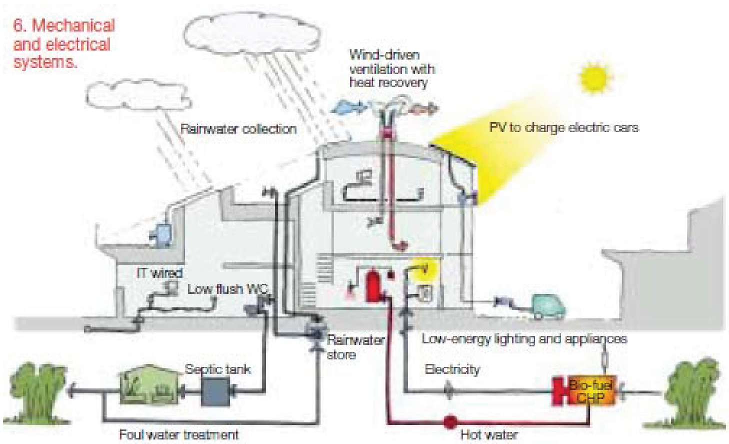


Figure 1 Generic scheme of the BedZED (Twinn, 2003)

A CHP like this works based on proprietary gasifier system which converts woodchips into a wood-gas that will fuel the CHP spark ignition engine (Twinn, 2003).

There are other examples like the Vatican. In the Vatican auditorium there have been installed photovoltaic panels, which produce 300 MWh per year (Inhabitat, 2009). The energy produced is used in the auditorium and when it is not being used, the power is stored in the Vatican's power network (BBC, 2008)

Figure 2 Photovoltaic panels in Vatican city (Inhabitat, 2014)

In Denmark, Samso Island has gone from a great consumer of coal and oil into an energy exporter. It uses wind turbines to produce electricity, solar panels and biomass to produce heat. Nowadays the island produces 10% more than it uses. Some of the wind turbines are off-shore (Biello, 2010).

Figure 3 Wind turbines off-shore in Samso, Denmark (Edinenergy, 2014)

Other example is Masdar city in Abu Dhabi, in which in the project phase was established zero-carbon, zero-waste, car-free municipality goals for 50 000 residents. This is a whole new city yet into construction process. The city electricity needs are intended to be supplied by photovoltaic panels and wind towers.

Another example is the district heating in Sheffield, which is based on the process of co-generation which is the use of heat that results from transformations processes such as incineration, and use it to heat water that circulates in pipe grids which supply the buildings. Figure 4 shows a generic scheme of the Sheffield cogeneration process.

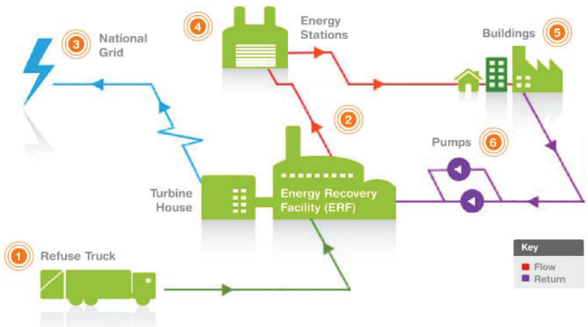


Figure 4 Key components of district heating process in Sheffield (Finney, Swithenbank & Sharifi, 2011)

Table 1 summarizes the characteristics of the district technologies above mentioned. The case of Masdar has not been included, once it is still in construction and there is not a feedback of the cities real performance.

Table 1 Summary of the district technologies above mentioned

| Name | Dimensions | Type of system | Produced energy |
|---|---|---|---|
| Western Harbour, Malmo, Sweden | Serves 1000 dwellings | Thermal aquifer supported by heat pumps with COP 3.15; 120 m² of photovoltaic; 1400 m² solar collectors and wind power | 3900MWh/y for heating, 3400MWh/y for cooling and the PV and wind power produce 100% of the electrical energy |
| BedZED, UK | Serves 220 residents (99 homes) and 100 office workers | 130 kW biomass combined heat and power plant (CHP); 777m² of photovoltaic panels | 88.000 kWh of electricity from the PV panels. CHP is not working properly |
| Vatican | 2400 photovoltaic panels | Photovoltaic systems | 300 MWh/y of electrical energy (equivalent to annual needs of 100 households) |
| Samso, Denmark | 11 onshore and 10 offshore wind turbines (34 MW) | Wind turbines for electricity/ solar panels and biomass for DH | 1 MW wind turbine powers 630 homes |
| Sheffield, UT | Network Pipelines with 44 km, serving 140 buildings and 3000 residential environments | Combined heat power plant (CHP) | 60MW of thermal energy and 21MW of electrical energy |

## 3 COST OPTIMAL METHODOLOGY

To evaluate the potential of energy performance improvement on existing buildings, the case of a social neighbourhood has been analysed. Using the cost-optimal methodology (EC, 2012), the cost-optimal solutions including renewable systems at building scale and at district scale, are compared. The analysis starts with the energy characterization of each building, with the calculation of the energy needs following the Portuguese thermal building regulation, which is based on the ISO-13790.

After this energy characterization it is necessary to establish renovation measures which are able to improve the energy performance of the buildings. Usually these measures are targeted to improve the energy efficiency of the components of the buildings envelope (walls, roof, floor and windows). The chosen renovation measures always affect more than one of the buildings elements. For each package of energy efficiency measures, different combinations of building integrated technical systems (BITS) for heating, cooling and DHW are tested and individual and district renewable energy systems are considered. For each building renovation scenario, the energy use for heating, cooling and DHW is calculated and the non-renewable primary energy use is derived. The conversion factors are 2.5kWh$_{PE}$/m².y per kWh/m² for electricity and 1kWh$_{PE}$/m².y per kWh/m² for gas (MEE, 2013).

The next step is to calculate the global costs for each renovation scenario. The global costs depend on the initial investment and on the costs related to the measures during the buildings life cycle (EC, 2012). The energy evolution of costs follows the predictions of the UE trends 2030 (European Commission, 2009) and 2050 Roadmap for the electricity and the IEA Energy Outlook 2011 for the gas (IEA, 2011). The biomass costs are based on the Portuguese market costs. The initial investments and maintenance costs were based on the Cype® software for generating prices (CYPE, 2014). The costs of the district solution with solar panels follow a reference value from CANSIA Solar Thermal Community Action Manual (CANSIA, 2008). The solution with the lowest global cost is the cost-optimal solution.

With the calculation of the primary energy use and global costs for each renovation measure, it is possible to determine the cost optimal measures for each building, by comparing it to other analysed renovation measures. This process is based on the cost optimal methodology proposed by the European Commission Delegated Regulation nº 244/2012 (EC, 2012). The same methodology can be used at a neighbourhood scale with the right adjustments on the investments and maintenance of the district system.

At the end it is possible to compare the global costs, at building scale and at neighbourhood scale, for each renovation solution.

## 4 CASE STUDY

### 4.1 Buildings characterization

The analysed case study is a social housing neighbourhood called Rainha Dona Leonor. It is located in Porto, Northwest of Portugal, and it was built in 1953. It has blocks of apartments and villas. The part of the neighbourhood used for the study consists of twenty two villas, which used to have four apartments each, divided by two floors.

The villas no longer comply with the current living patterns and the four apartments were converted in two, one in each floor. Besides these changes, the project also includes improvements on the buildings envelope. Most of the villas are semi-detached houses or row houses. The envelope did not have any insulation and there were wooden window frames with simple glazing and external plastic shutters. The system for DHW production was an electric heater with storage tank and there were no heating/cooling systems apart from portable electric heaters or fan coils. Figure 5 shows the horizontal plant of the neighbourhood.

Figure 5 Neighbourhood horizontal plan

## 4.2 Renovation process and alternative scenarios

The implemented renovation solution includes ETICS with a 6 cm thick layer of EPS in the exterior walls, XPS with 5 cm in the roof, wooden frame windows with double glazing and a new electrical water heater with storage tank. For heating, the renovation solution considered HVAC system with multi-splits. It also includes solar panels for DWH pre-heating. Table 2 shows the energy needs, the primary energy use and emissions for the initial situation of the building and considering the above mentioned renovation solution (after renovation).

Table 2 Summary of energy needs and carbon emissions before and after renovation

| | Heating needs (kWh/m².a) | Cooling needs (kWh/m².a) | DHW (kWh/m².a) | Primary energy use (kWh/m².a) | Emissions (Ton eq $CO_2$) |
|---|---|---|---|---|---|
| Before renovation | 84 | 17 | 29 | 478 | 24 |
| After renovation | 33 | 11 | 29 | 292 | 14 |

Table 3 Summary of the analysed measures for the buildings envelope

| | Roof | Wall | Floor | Window |
|---|---|---|---|---|
| Base | XPS 5cm | EPS 6cm | _ | _ |
| M1 | RW 8cm | _ | _ | _ |
| M2 | RW 14cm | _ | _ | _ |
| M3 | RW 14cm | _ | RW 4cm | _ |
| M4 | RW 14cm | _ | RW 8cm | _ |
| M5 | RW 14cm | EPS 4cm | RW 8cm | _ |
| M6 | RW 14cm | EPS 10cm | RW 8cm | _ |
| M7 | RW 14cm | EPS 10cm | RW 8cm | PVC 2,4 |
| M8 | RW 14cm | EPS 10cm | RW 8cm | PVC 2,1 |
| M9 | RW 14cm | EPS 10cm | RW 8cm | PVC 2,0 |
| M1a | ICB 4cm | _ | _ | |
| M2a | ICB 8cm | _ | _ | |
| M3a | ICB 8cm | _ | ICB 4cm | |
| M4a | ICB 8cm | _ | ICB 8cm | |
| M5a | ICB 8cm | ICB 4cm | ICB 8cm | |
| M6a | ICB 8cm | ICB 8cm | ICB 8cm | |
| M7a | ICB 8cm | ICB 8cm | ICB 8cm | wood 2,9 |
| M8a | ICB 8cm | ICB 8cm | ICB 8cm | wood 2,5 |
| M9a | ICB 8cm | ICB 8cm | ICB 8cm | wood 2,4 |

Taking the implemented renovation solution as base solution, alternative renovation scenarios were analysed. The analysed measures and BITS are presented in tables 3 and 4. The alternative scenarios result from the combination of each BITS with each one of the envelope solutions. In table 3, the base solution is the chosen renovation solution. Given the buildings thermal inertia and the implementation of insulation in the roof, the thermal regulation does not consider the cooling energy needs. Therefore the BITS combinations do not present a system to deal with the cooling needs.

The results of the cost-optimal analysis at building scale are presented in figure 6. In the figure, each group of markers corresponds to each one of the BITS combinations. Inside each group of markers, each point is one of the analysed combinations for the buildings envelope.

Table 4 Summary of the analysed BITS at building scale

| | Heating | Cooling | DHW | Renewable |
|---|---|---|---|---|
| BITS 1 | Gas boiler | _ | Gas boiler | _ |
| BITS 2 | Heat pump | _ | Heat pump | _ |
| BITS 3 | Heat pump | _ | Heat pump | PV |
| BITS 4 | Biomass boiler | _ | Biomass boiler | _ |
| BITS 5 | Electric heaters | _ | Electric heater | ST |

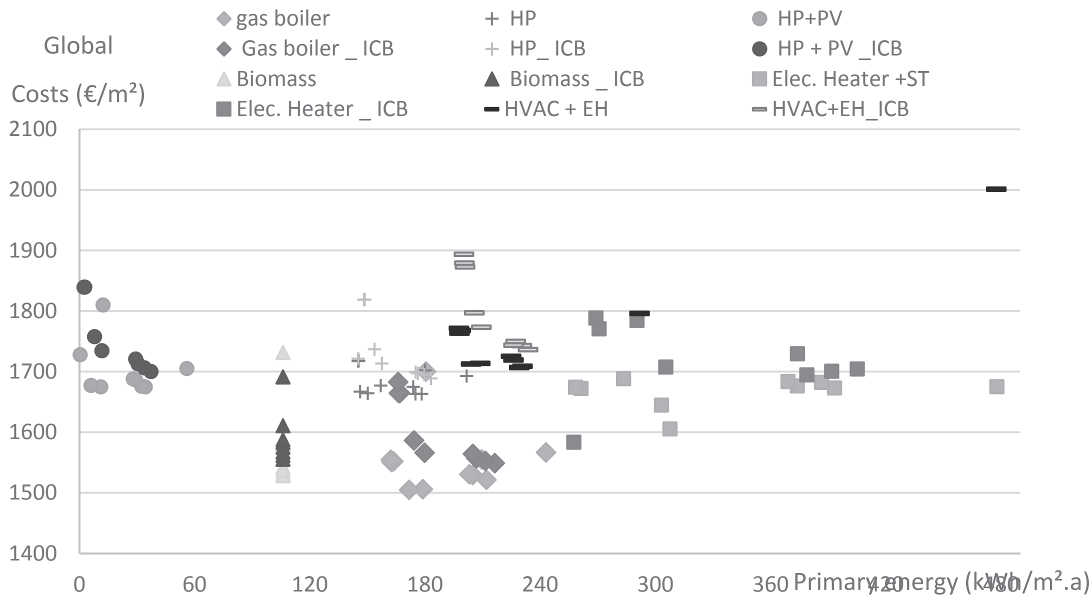

Figure 6 Cost optimal results for the analysed renovation scenarios at building scale

Looking at figure 6 it is possible to see that the cost optimal solution (marker with lowest global costs) includes the gas boiler for heating and DHW, with ETICS with 10cm of EPS for the external walls, 14cm of rock wool in the roof and 8cm of rock wool on the floor. The window solution is similar to the existing one. The second best solution concerning the BITS is the biomass boiler for heating and DHW.

### 4.3 Cost optimal for neighbourhood scale

Considering the same renovation measures for the buildings envelope this analysis intended to understand the potential of applying community solutions to fulfil the energy needs for heating and DHW. The most common solutions in Portugal are photovoltaic panels and solar thermal panels. The heat district and CHP are just giving their first steps. For this study, a solution of solar thermal panels that produce DHW to the whole neighbourhood, including a storage tank, was considered. This system is backed by individual electric heaters in each of the dwellings. The results are presented in figure 7, with the analysed renovation measures with solar thermal system at building scale and also at neighbourhood scale.

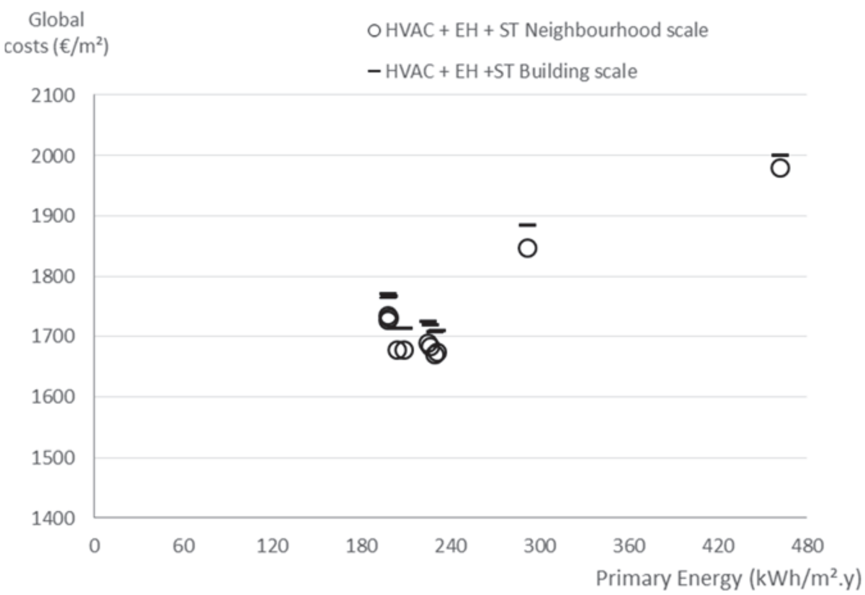

Figure 7 Cost optimal results for the analysed renovation scenarios at neighbourhood scale

Comparing the results of the building scale and the neighbourhood scale, it is possible to see that for the same combination of BITS, with a solar thermal system for the whole neighbourhood, the global costs are lower around 40 €/m² at the neighbourhood scale. The cost-optimal solution for the renovation of the building envelope does not suffer changes with the introduction of this neighbourhood scale system meaning that the cost optimal solution is the same considering either the building or the neighbourhood scale.

## 5 CONCLUSIONS

District energy is not new, with many systems implemented during the 20th century in several countries around the world, but has been recently gaining interest because of the increasing emphasis on energy efficiency, environmental performance, and the growth of on-site renewable energy sources that present challenges regarding their integration in global grid.

The district energy systems have the ability of tackling large-scale energy problems on a local level, with local resources allowing providing energy more efficiently, more resiliently, and emitting less carbon into the atmosphere than building scale systems. The benefits of district energy systems include lower investment costs for building owners or promoters as they do not need to provide individual systems, elimination of space normally used in buildings for individual systems and might result in cheaper energy for the end users due to economies of scale, higher operating efficiencies, and the potential to use lower-cost, primary-energy sources.

Major problems with the diffusion of these systems are the high investment costs and the economic risks related to building loads not happening as planned or reduction of building loads due to changes is the use of energy by the buildings users. In Portugal, although the traditional cultural accommodation to low comfort levels block the opportunity of using these systems for heating or cooling, for DHW preparation (as presented in this paper with solar thermal) or electricity generation, the solar potential of our climate and the high energy prices present a real opportunity that worth exploring to deal with the growing demand for energy, the dependency on depleting fossil fuels, and climate change.

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